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PROPULSION SHAFTING ARRANGEMENT AND ALIGNMENT

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and
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PROPULSION SHAFTING ARRANGEMENT AND ALIGNMENT

by

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(1953)

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PROPULSION SHAFTING ARRANGEMENT AND ALIGNMENT, by WILLIAM D. MARKLE and GRAEME MANN. Submitted to the Department of Naval Architecture and Marine Engineering on 21 May 1960 in partial fulfillment of the requirements for the Master of Science degree in Naval Architecture and Marine Engineering and the Professional Degree, Naval Engineer.

ABSTRACT

The object of this investigation was to determine the feasibility of increasing the shaft system flexibility through use of increased lineshaft bearing spans. It is proposed that this increased flexibility will result in a shaft system which is less sensitive to initial misalignment and to misalignment resulting from hull deflections, thermal effects and bearing wear. The effect of variation of system dimensions and loading, as they influence the shaft system alignment and strength, are investigated and a design formula is proposed which accounts for the effect of alignment on shaft stress.

The investigation is based on the analysis of a representative family of shaft systems which are developed from statistical data for single screw solid shaft systems. The analysis uses vertical alignment of the first lineshaft bearing to provide equal gear bearing loads. Limitations of natural frequency, bearing loads and combined stress are imposed throughout the analysis.

The results of the investigation indicate that the use of increased lineshaft spans is very feasible. Under the imposed condition that the lineshaft bending moment be equal to that produced by the propeller overhang, lineshaft span to diameter ratios were obtained which represent a minimum increase of 23 per cent over the values indicated by statistical data.

It is shown that the design, arrangement of bearings and alignment of the shaft must be considered concurrently. It was further ascertained that there is a direct relationship between alignment and shaft strength. For the alignment condition imposed, it was determined that the use of the relationship

$$M_b = \frac{3 W L^2}{16}$$

in computing the shaft diameter by means of combined stress, will provide for the increase in stress created by the alignment procedure. Also determined was the fact that the variation of all other major geometries of the systems had no effect upon this relationship.

It is qualitatively shown that an improved alignment, making use of vertical adjustment of all bearings to meet the gear alignment criteria, will reduce the value of the coefficient in the above relationship. It is therefore recommended that further studies be conducted to evaluate the coefficient for other conditions of alignment.

Pending additional study, it is recommended that bearing span to diameter ratios of 20 be adopted for single screw ships and that the shaft diameter be computed by combined strength using the above relationship.

Thesis Supervisor: S. Curtis Powell

Title: Associate Professor of Marine Engineering

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LIST OF SYMBOLS

B = number of propeller blades
Cb = block coefficient

Dgs = gear shaft diameter, inches
Dh = equivalent bull gear diameter, inches
Dls = lineshaft diameter, inches
Dts = tailshaft diameter, inches
Dp = propeller diameter, inches
d = inner diameter of shaft, inches

E = modulus of elasticity, psi
e = thrust eccentricity, inches
EHP = effective horsepower

f = natural frequency of lateral vibration, cpm
F.S. = factor of safety

G = modulus of shear, psi

I = moment of inertia of shaft about diameter, in^4
Ix = mass moment of inertia of propeller about diameter, $lb\ in\ sec^2$

Kb = stress concentration factor in bending
Kt = stress concentration factor in shear

L = total length of shaft system, inches
Ln = length between lineshaft bearings, inches
Ll = length between stern tube bearings, inches
Lb = length between reduction gear bearings, inches
Lf = length of bull gear face, inches
Lp = propeller overhang, inches

Mb = shaft bending moment, Kip-in
Mg = bending moment due to propeller overhang = $W_p L_p$ Kip-in
Moc = bending moment due to off center thrust, Kip-in
Mp = Mg + Moc, Kip-in
m = mass, $\frac{lb\ sec^2}{in}$

N=RPM=shaft revolutions per minute

P.C. = propulsive coefficient
p = pressure, psi

Q = mean or steady torque, in-lb

R = bearing reaction, lb.
RIN = reaction influence number
r = radius of gyration of propeller, inches

SHP = shaft horsepower

$T=Tt$ = propeller thrust, lb.
t = thrust deduction

V_k = ship speed, knots

W_p = weight of propeller in air, lb
W_p^* = weight of propeller in water, lb
W_g = weight of bull gear assembly, lb
ΔW_g = W_g (-) weight of equivalent gear assembly, lb
W_{ts} = weight of tailshaft, lb per inch
$W_p r^2$ = mass moment of inertia of propeller about its axis, lb in^2

σ_{ar} = resultant alternating stress, psi
σ_b = compressive stress due to bending, psi
σ_c = compressive stress due to thrust, psi
σ_s = shear stress due to torsion, psi
σ_{sr} = resultant steady stress, psi
σ_{sa} = alternating shear stress, psi
σ_{yp} = yield point stress, psi
σ_{fl} = fatigue or endurance limit, psi

ϕ = vibration amplitude, radians

I.

INTRODUCTION

1. Background

In past years, notable advances have been made in the field of marine propulsion machinery. In particular, propeller and gear design has progressed to a highly refined state. However, propulsion shafting design has been considered primarily with regard to strength considerations. There has been little concern as to the overall effect of the shaft design arrangement upon the power transmission system. Only in very recent years has interest developed in the alignment and arrangement of the shafting system and their integrated effect upon the overall design and performance of the system.

Prior investigations of the subject, (1), (5)* indicate that a deficiency exists in our knowledge of shaft behavior as it effects the design, arrangement, and shipboard alignment of the shaft system. At present, the shafting system is not being designed as an integrated system.

---

* () indicates literature citations as noted in the Bibliography.

In numerous cases, (1), (5), this has resulted in a system of such poor design and arrangement that it has been impossible to achieve an alignment which would give satisfactory performance of bearings, reduction gear and other attached propulsion units.

Similarly, there are no well defined alignment criteria. Most shipyards have their own particular alignment procedures based on past experience and tradition. Many of these procedures involve the use of equipment and concepts which are obsolete (3).

2. Effects of Misalignment

Some of the more important effects of misalignment are:

(a) Improper loading of reduction gear bearings resulting in mismatch of gear teeth. This leads to uneven or excessive wear, a high noise level and in severe cases to ultimate tooth failure.

(b) Unloading of stern tube and/or line shaft bearings causing vibration, leakage of stern tube packing and damage to bearings.

(c) Overloading of bearings causing excessive heating, or failure, and in the case of stern tube bearings, accelerated weardown.

The invididual problem areas are discussed in detail in Appendix "A".

3. Factors Influencing Alignment

Numerous factors influencing the final alignment and performance of the shaft system are of an unpredictable nature, or time variant. Therefore, even if it were possible to obtain an initially perfect alignment, at some later time the system may be subject to severe conditions of misalignment.

Bearing movement may be caused by hull deflection or by movement of the bearing relative to the hull. When a ship is sitting on the blocks its hull undergoes continual deflection due to the heating effects of the sun. Similar deflections are realized with the ship afloat. Docking, undocking, and changed loading also produce deflection of the hull through the obvious effects of the load and buoyancy distribution. Even more pronounced effects may be experienced when the ship is underway, working in a seaway.

During operation, bearing wear produces an effective movement of the shaft support points relative to the hull which results in a shift of the distribution of bearing loads. This effect is greatest for water-lubricated bearings and practically negligible for oil-lubricated bearings. Relative bearing movements may also be caused by thermal expansion of reduction gear casings or of any other bearing foundations which are subject to thermal effects.

4. Object of the Thesis

In appreciating the above causes and effects, it is apparent that needless time and money may be expended aligning and realigning bearings in an attempt to obtain satisfactory operating conditions unless the shaft system is designed to be insensitive to reasonable degrees of misalignment.

This thesis proposes that the problems associated with alignment may be reduced by increasing the span between line-shaft bearings. The feasibility of the proposal is investigated by the use of a representative family of shaft systems developed and analyzed, subject to limiting criteria. The effect of alignment upon shaft stress is investigated and the effect of system geometry on alignment is considered.

It is anticipated that the use of shaft systems with increased line-shaft spans will lead to higher permissible bearing loads, increased wear limits for water-lubricated bearings and quieter gear operation.

II.

THEORY

1. The Basic Theory

All of the problems encountered with shafting systems appear to be directly, or indirectly, related to the stiffness of the system as designed and installed. Since the shaft system is basically a continuous beam of finite length, it is proposed that the system stiffness may be controlled by varying the support spacing. This in effect says that, if I/L_n of the shaft is decreased the system becomes more flexible. The same effect could be accomplished by decreasing the shaft inertia, but this would result in a decrease in shaft strength. In a similar sense it must be realized that an increased shaft span will result in increased shaft stress and requires an increase in I. It may therefore be stated that I is the dependent and L_n the independent variable. The shaft system, however, represents a continuous beam of non-uniform loading and support spacing. Under these conditions I/L_n does not give a true picture of the overall system stiffness.

A more representative, but equivalent, measure of the system flexibility is obtained by a collective consideration

of the support reaction influence number (RIN) matrix.* High reaction influence numbers indicate a high shaft sensitivity to misalignment, while lower influence numbers indicate low sensitivity. Low RIN's mean that greater alignment may be absorbed by the system without significantly changing the bearing loads or the shaft stress. This in turn indicates that the system factors of safety (F.S.) are maintained at near designed values for moderate degrees of misalignment. Just as I/L_n may be reduced by increased support spacing, so may the reaction influence numbers be lowered. The exact, generalized, trend of RIN, or I/L_n, with variation of span remains to be determined by analysis of the shaft system. Qualitatively this trend has been recognized in previous investigations, (1), (5). However, these investigations were specific in nature and did not consider the system as an integrated design.

2. Alignment Theory

For the purposes of this study alignment shall be considered as a matter of vertical bearing position. Initially the bearings may be assumed to be aligned when they all lie on a straight line in the vertical plane. Such alignment is referred to as "straight line alignment". Any deviation

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* For definition of Reaction influence numbers, refer to the Theory of the Computer Program, Appendix "G".

from this line is considered a misalignment and in the past has been considered detrimental to the system performance. However, it has been shown, (5), that intentional misalignment, when properly used, acts in a manner to benefit the overall shaft system. Such intentional misalignment is referred to as "fair curve alignment". The use of this "fair curve alignment" theory is essential to the success of the basic theory.

It must be realized that as L_n is increased and the RIN's lowered, the effect of localized loading will be most pronounced on the bearing in that vicinity. Effectively the high RIN's restrict the distribution of the moments induced by the shaft loads. While this may be of considerable benefit in the region of the propeller, it creates a major problem in the gear region.

As the first lineshaft span aft of the gear is increased, the load differential of the gear bearings increases. If the span is decreased to obtain a favorable split of gear bearing loads, the system becomes overly sensitive to the slightest misalignment. The most logical means by which this conflict may be resolved is through recourse to the theory of "fair curve alignment". Basically this involves vertical alignment of the line-shaft bearings in such a manner as to maintain the desired bearing load distribution.

3. Limitations

If no limitations were imposed upon the basic theory, the bearing span could be increased indiscriminately. However, numerous limitations exist which may act individually, or in combination, to restrict the variation of the span. These limitations are therefore developed in the sense that they will be used to further investigate the feasibility of the basic theory.

Maximum allowable combined shaft stress

The maximum allowable combined shaft stress may be calculated in numerous ways. For the purpose of this investigation the combined stress theory used by the Bureau of Ships, United States Navy, (7), appears most inclusive and is adopted. This theory states that

$$\frac{\sigma_{steady}}{\sigma_{yp}} + \frac{\sigma_{alt}}{\sigma_{fl}} = \frac{1}{F.S.} \qquad (1)$$

where

$$\sigma_{steady} = \sqrt{\sigma_c^2 + (2\sigma_s)^2} \qquad (2)$$

and

$$\sigma_{alt} = \sqrt{(k_b \sigma_b)^2 + (2K_t \sigma_{sa})^2} \qquad (3)$$

When L_n is increased, the alternating bending component of the stress, σ_b, is increased proportional to L_n^2.

Vertical alignment of the shaft will cause a further change in bending stress. Other stress components will remain unchanged.

Since the combined stress solution and the determination of the shaft diameter are interrelated, it is possible to vary L_n as desired so long as the diameter is varied simultaneously.

Reduction gear alignment criteria

The manufacturer generally specifies a maximum allowable load and load differential for the bull gear bearings. Within these allowable limits the gear should not experience detrimental misalignment due to cocked gear and meshing pinions. The values of these limitations are determined by the manufacturer on the basis of gear loading, bearing clearance, and permissible misalignment of gear teeth, but the following are typical.*

Maximum allowable load differential ..... 5000 lb. (R.G. hot)

Maximum allowable gear bearing pressure .. 150 psi (R.G. hot or cold)

To meet these limitations some vertical alignment of the lineshaft is required which, as previously mentioned,

* Discussion with H.C. Anderson of the General Electric Co., Medium Steam Turbine and Gear Division and E. Antkoviak of the Boston Naval Shipyard, Design Division, Computer Application.

will alter the shaft stress. The most severe effect of this limitation upon the shaft stress occurs when a minimum "fair curve alignment" is used.

For this investigation the "minimum fair curve alignment" shall be that alignment in which only the first line-shaft bearing is adjusted vertically. It is recognized that a more satisfactory alignment can be achieved by adjusting the other bearings in the system in conjunction with the first line-shaft bearing, but this imposes less severe conditions on the system.

Lateral critical frequency of vibration

The calculated lateral critical frequency of vibration should not enter the operating range of the system. Current practice, based on past experience, indicates that satisfactory operation will occur if the calculated frequency is greater than 115% of the maximum shaft RPM. This lateral frequency is calculated for two cases, the tailshaft area and the line-shaft area:

Tailshaft (9)

$$f = \frac{30}{\pi} \sqrt{\frac{IE}{Ix\left(L_p + \frac{L_1}{3}\right) + \frac{W_p L_p^2}{g}\left(\frac{L_p}{2} + \frac{L_1}{3}\right) + m\left(\frac{L_p^4}{8} + \frac{L_1 L_p^3}{9} + \frac{7L_1^4}{360}\right)}} \qquad (4)$$

Line-shaft (App. B-2)

$$f = \frac{30}{\pi} \sqrt{\frac{EI\pi^4}{m L_n^4} - \frac{T \pi^2}{m L_n^2}} \qquad (5)$$

The frequency as calculated should be reduced by 60% to account for the unknown elastic and damping characteristics of the shaft bearings and supports.

It is recognized that formulas (4) and (5) are approximate; however, they are entirely satisfactory for this investigation.

It should be noted that formula (5) can also be interpreted as a measure of buckling stability. The limit of buckling stability is approached as the frequency goes to zero.

Bearing Load

The maximum allowable bearing load can limit the shaft span. The most difficult problem is to specify these maximum loads. Present practice is considered conservative, the following being typical maximum allowable pressures:

Water lubricated,	p (max.) $\approx$ 20 psi
Oil lubricated,	p (max.) $\approx$ 50 psi
Pressure oil lubricated,	p (max.) $\approx$ 150 psi

For equivalent land based application, such pressures are considered unusually low (6). Recent advances (1), (5) have shown that the bearing loads can be determined to a high degree of accuracy. In addition, with the increased spans proposed, there is less possibility of the bearing load changing due to misalignment caused by thermal effects, variation in hull loading, and effects due to working of the hull in a seaway. Finally, the shafting will be analyzed under "minimum alignment" conditions which produce the most severe loading on the bearings. Based on the above argument, bearing pressures up to about 100 psi (oil lubricated) will be considered as acceptable for line-shaft bearings.

The minimum bearing load is an equally important consideration, since inadvertent unloading of a bearing may cause serious damage. Experience indicates that a minimum bearing load of 2000-3000 lb. in the final aligned condition is satisfactory (1). Although not considered in this investigation, a more satisfactory loading will result if the bearings are equally loaded. In the same manner, a calculation of the bearing loading with maximum allowable stern tube weardown should be made.

4. The Representative System

An analysis of the shaft system as a continuous beam is impossible unless refinement is made with regard

to system loading. This requirement is imposed by the many unsolved problems which arise when considering the system and the ship jointly, in a time variant sense. These may be summarized as problems resulting from:

(1) Dynamic loading and deflection of the ship girder.

(2) Thermal deflection of the hull girder.

(3) Variation of the bearing loads due to system operation.

(4) Variation of hull induced hydrodynamic effects on exposed components of the shaft system.

Inasmuch as each of these problems involves a study in itself, it is assumed for the purposes of this investigation that the shaft system is a "statically loaded continuous beam". In actual practice, this assumption has produced satisfactory results (1), (5). This indicates that load variations due to these effects are usually quite small, since shafting is generally designed with a low F.S. $\approx$ 2.0.

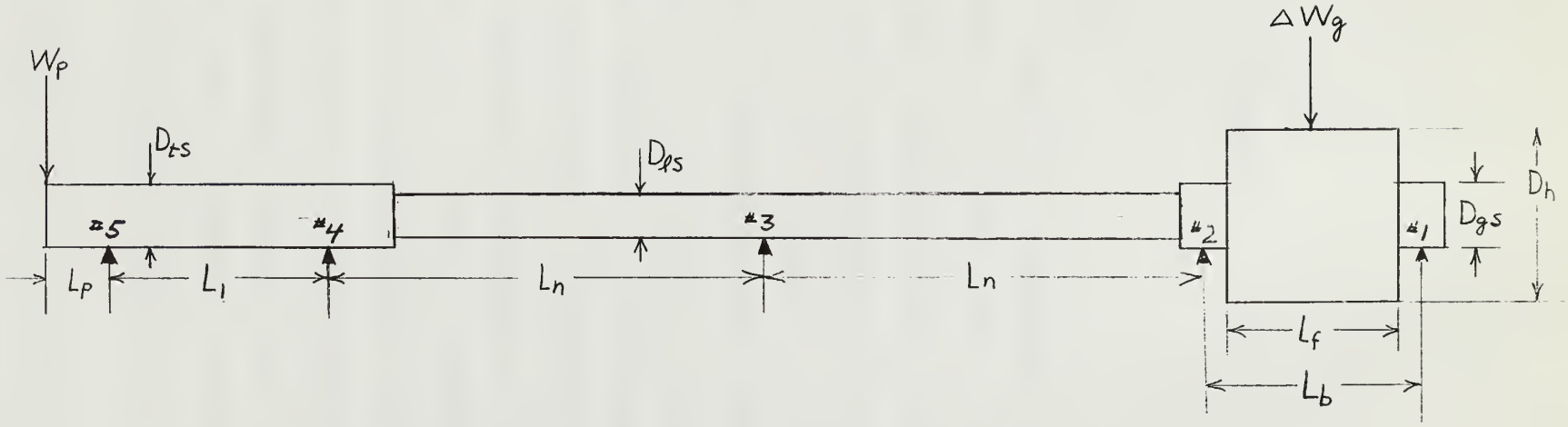
In order to generalize the problem, it is necessary to assume that the effects of small concentrated loads, such as shaft flanges and journal sleeves, are negligible compared to the concentrated loads of the propeller and gear and the distributed load of the shaft itself. Similarly, it is

necessary to neglect the localized effect of flanges and sleeves upon shaft stiffness. This latter assumption will, in reality, closely approximate the actual conditions that exist because of the short length of flanges and the low degree of fixity of the sleeves. For the purposes of a generalized approach both assumptions are considered reasonable. Their effect on qualitative results should be completely negligible and quantitative results should be effected only slightly.

Also, in order to obtain a representative system, it is necessary to distinguish between single and multi-screw shaft systems and solid or hollow shafts. The very nature of this problem could greatly extend the scope of the analysis if each combination were considered separately. For this reason a brief preliminary analysis was made in order to determine which type of system could be expected to produce the most severe problems as regards shaft stiffness (App. B.3). It was decided that the solid single screw system presented the most severe conditions due to (a) higher w/I, (b) shorter overall shaft length and (c) heavier concentrated gear and propeller loads. This decision was further influenced by the type of ship for which data was available locally.

The final representative shaft system is shown in Figure I.

FIGURE I
REPRESENTATIVE SHAFT SYSTEM



III.

PROCEDURE

1. Method of Solution

In order to determine the general feasibility of the basic theory, subject to limitations, a solution of the representative shaft system as shown in Figure I is necessary. Several possible approaches were considered; however, the only method which appeared practical was that based on a family of representative shaft systems. This method of analysis is made possible by the existence of a computer program (Appendix "G") which permits the rapid solution of a large number of problems. The program was originated and developed by personnel of the Boston Naval Shipyard. The Bureau of Ships, United States Navy, arranged to provide the required computer time on the Datatron 205 computer located at the Boston Naval Shipyard.

The use of the family approach was adopted partly out of expedience and partly because it included the possibility of realizing some design criteria which could be of general use.

In order to make use of the program the various dimensions and weights of the shaft systems are required

input information: They are:

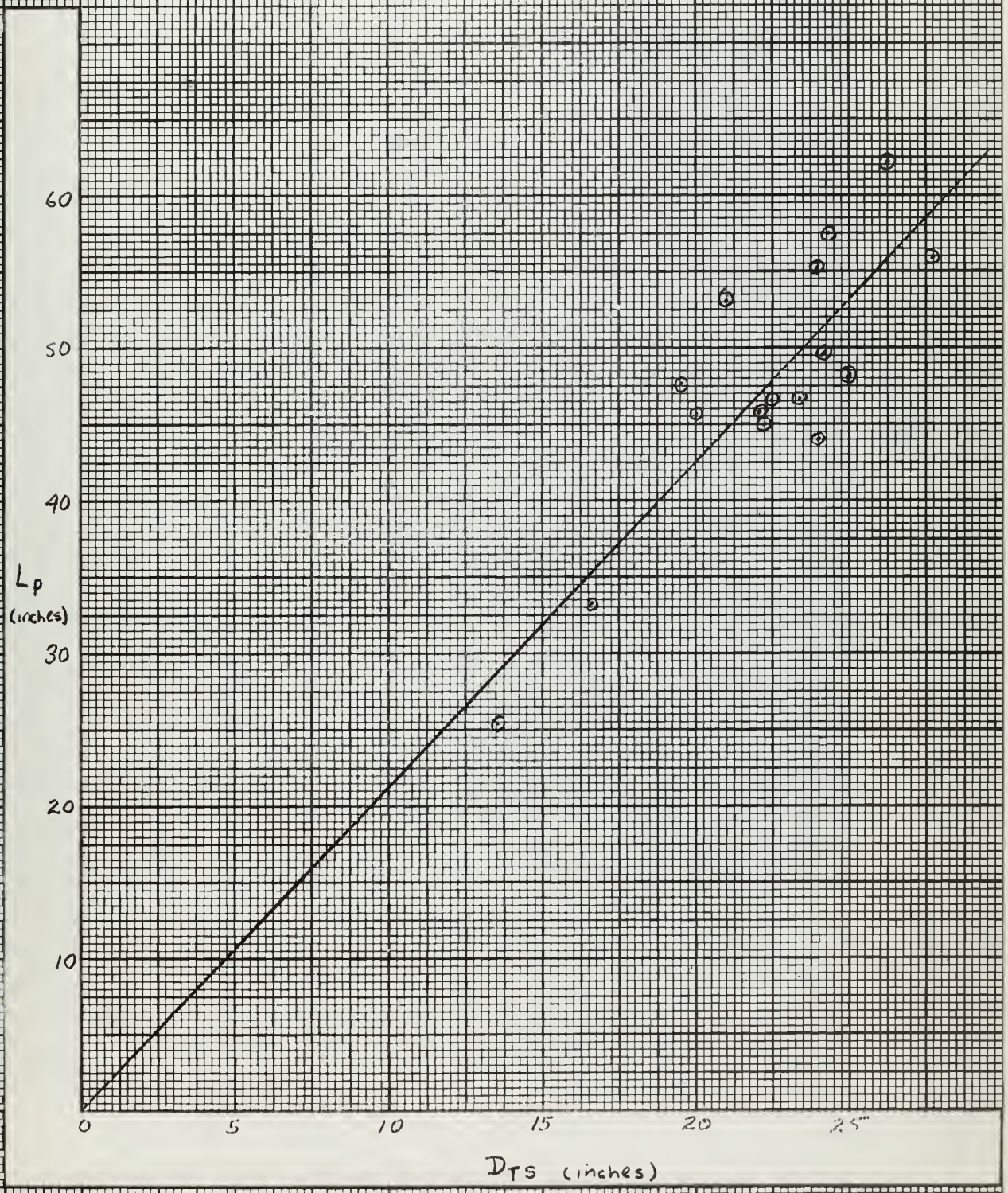
1. Length of system (L)
2. Length between lineshaft bearings (L_n)
3. Length between stern tube bearings (L_1)
4. Length from aft stern tube bearing to propeller (L_p)
5. Length between bull gear bearings (L_b)
6. Length of gear face (L_f)
7. Weight of reduction gear (W_g)
8. Weight of propeller (W_p)
9. Gear Shaft diameter (D_{gs})
10. Equivalent bull gear diameter (gear stiffness) (D_h)
11. Lineshaft diameter ($D_{\ell s}$)
12. Tailshaft diameter (D_{ts})

2. Reduction of Variables

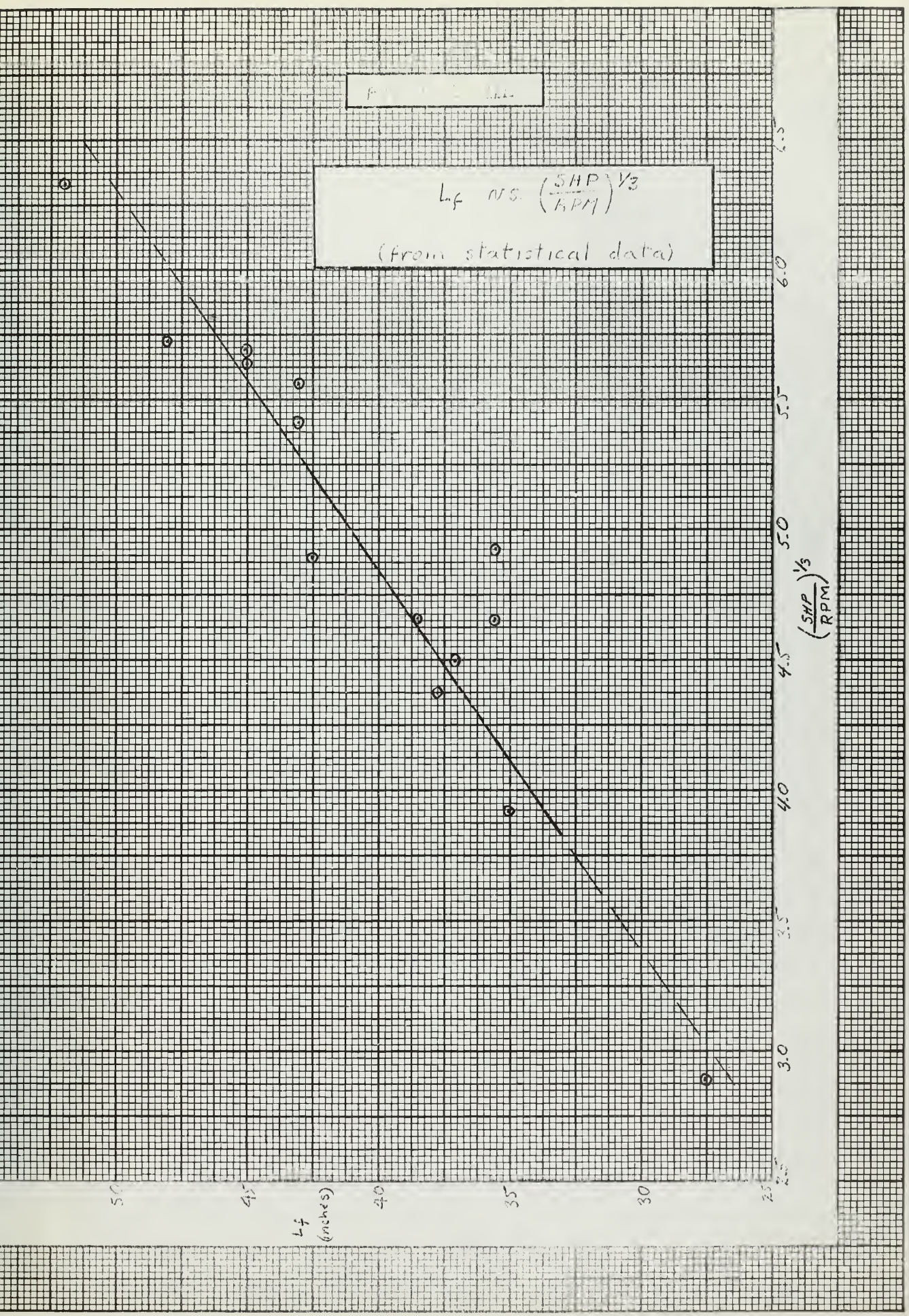
It was immediately realized that, to analyze a family of representative systems, the total number of system variables would have to be reduced. However, for different classes of ships (e.g., merchant and combatant) the design concepts, by which the variables are determined, are quite different. It was therefore decided that the study should be centered around that class whose shaft system most closely

FIGURE II

PROPELLER OVERHANG VS TAIL SHAFT DIAMETER
(From statistical data)



2/9/60 JMc


L_f vs. $\left(\frac{SHP}{RPM}\right)^{1/3}$
(from statistical data)
L_f (inches)
$\left(\frac{SHP}{RPM}\right)^{1/3}$
50
45
40
35
30
6.0
5.5
5.0
4.5
4.0
3.5
3.0

3/6/60 WDM

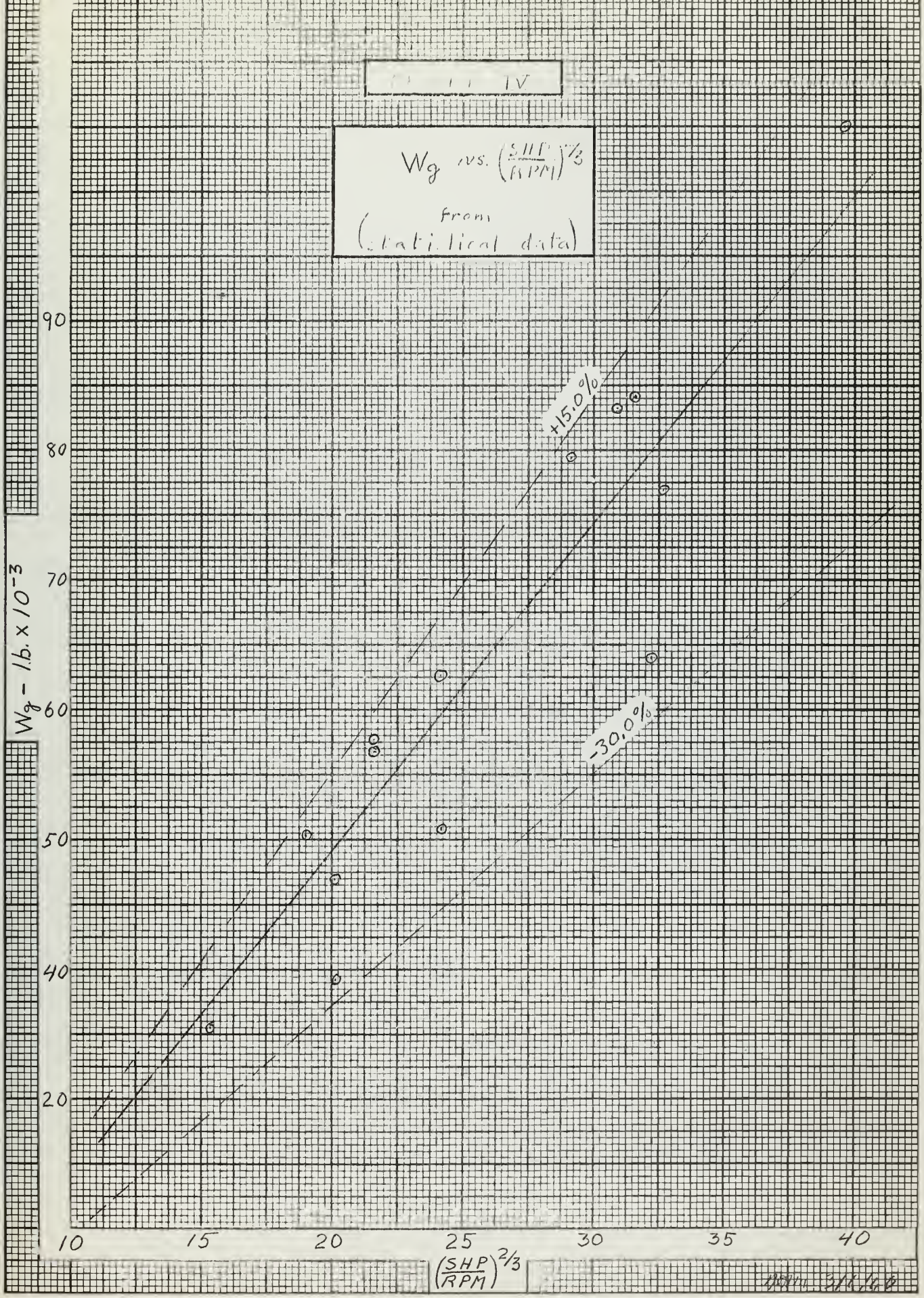


Plate IV
W_g vs. $\left(\frac{SHP}{RPM}\right)^{2/3}$
From
(statistical data)
+15.0%
-30.0%
W_g - lb. x 10^{-3}
90
80
70
60
50
40
20
10
15
20
25
30
35
40
$\left(\frac{SHP}{RPM}\right)^{2/3}$

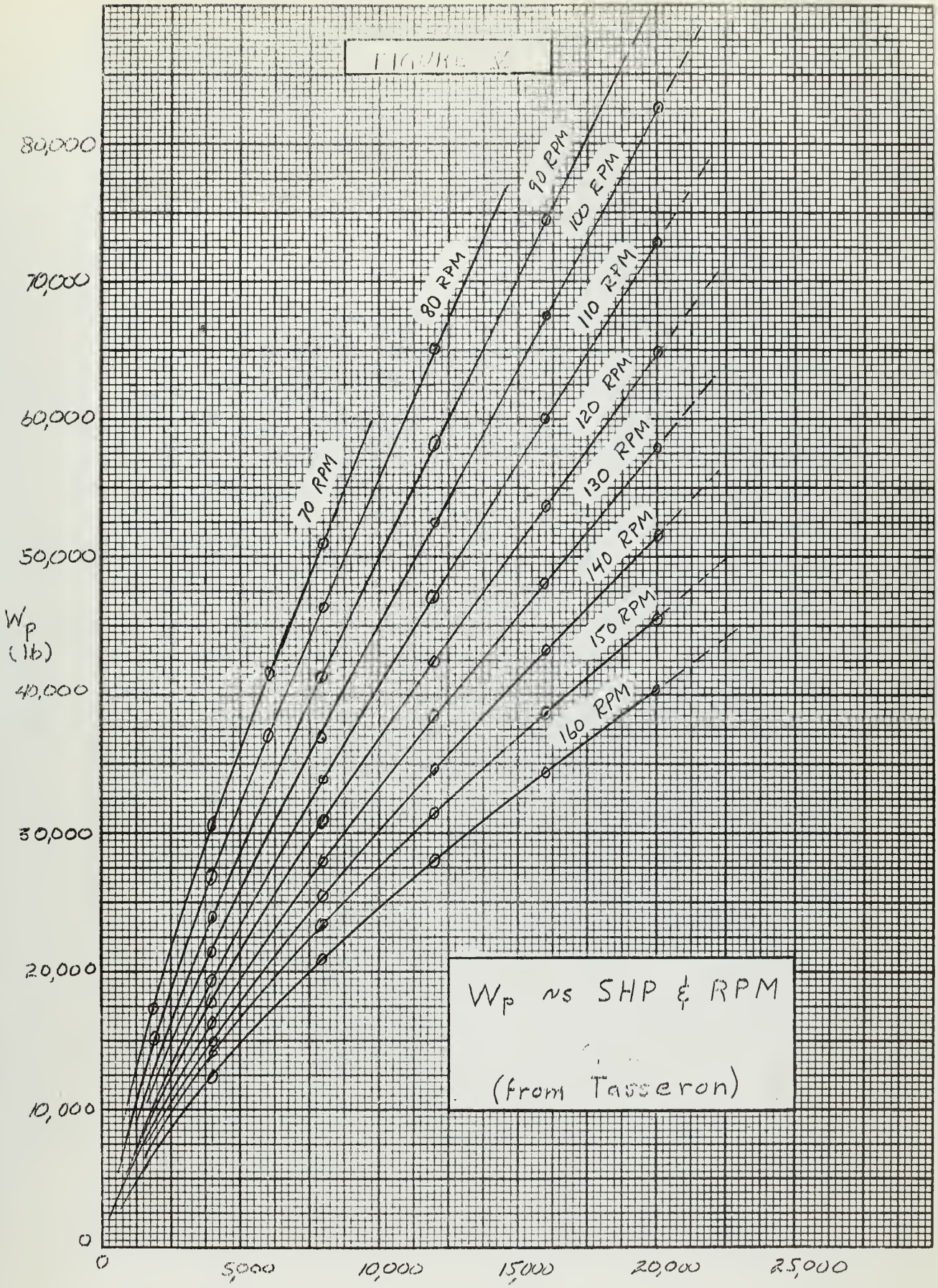


FIGURE X
80,000
70,000
60,000
50,000
W_p (lb)
40,000
30,000
20,000
10,000
0
0
5,000
10,000
15,000
20,000
25,000
SHP
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM
140 RPM
150 RPM
160 RPM
W_p vs SHP & RPM
(from Tasseron)

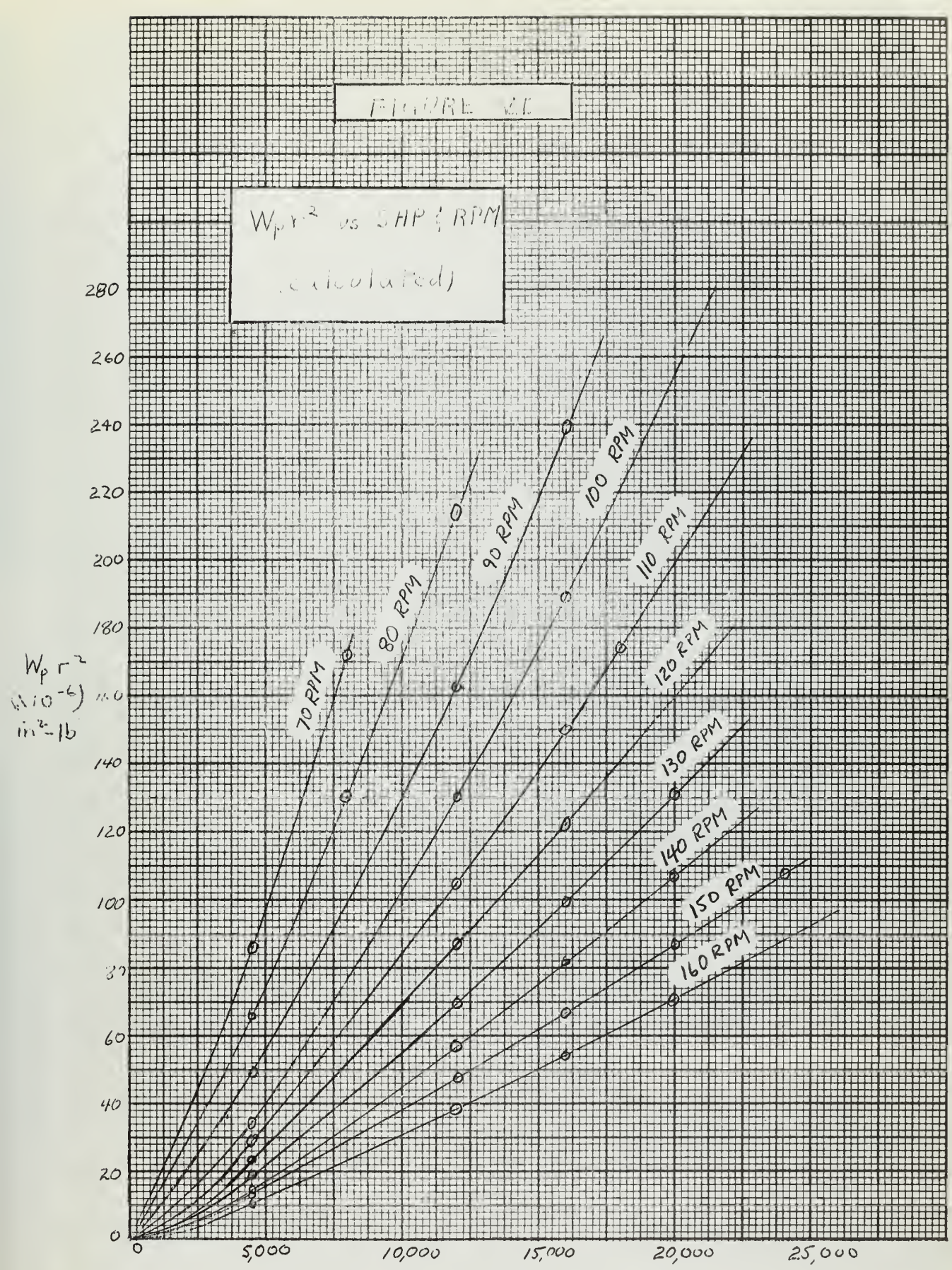


FIGURE 11
$W_p r^2$ vs SHP & RPM
(calculated)
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
$W_p r^2$
($\times 10^{-6}$)
in^2-lb
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM
140 RPM
150 RPM
160 RPM
0
5,000
10,000
15,000
20,000
25,000
SHP

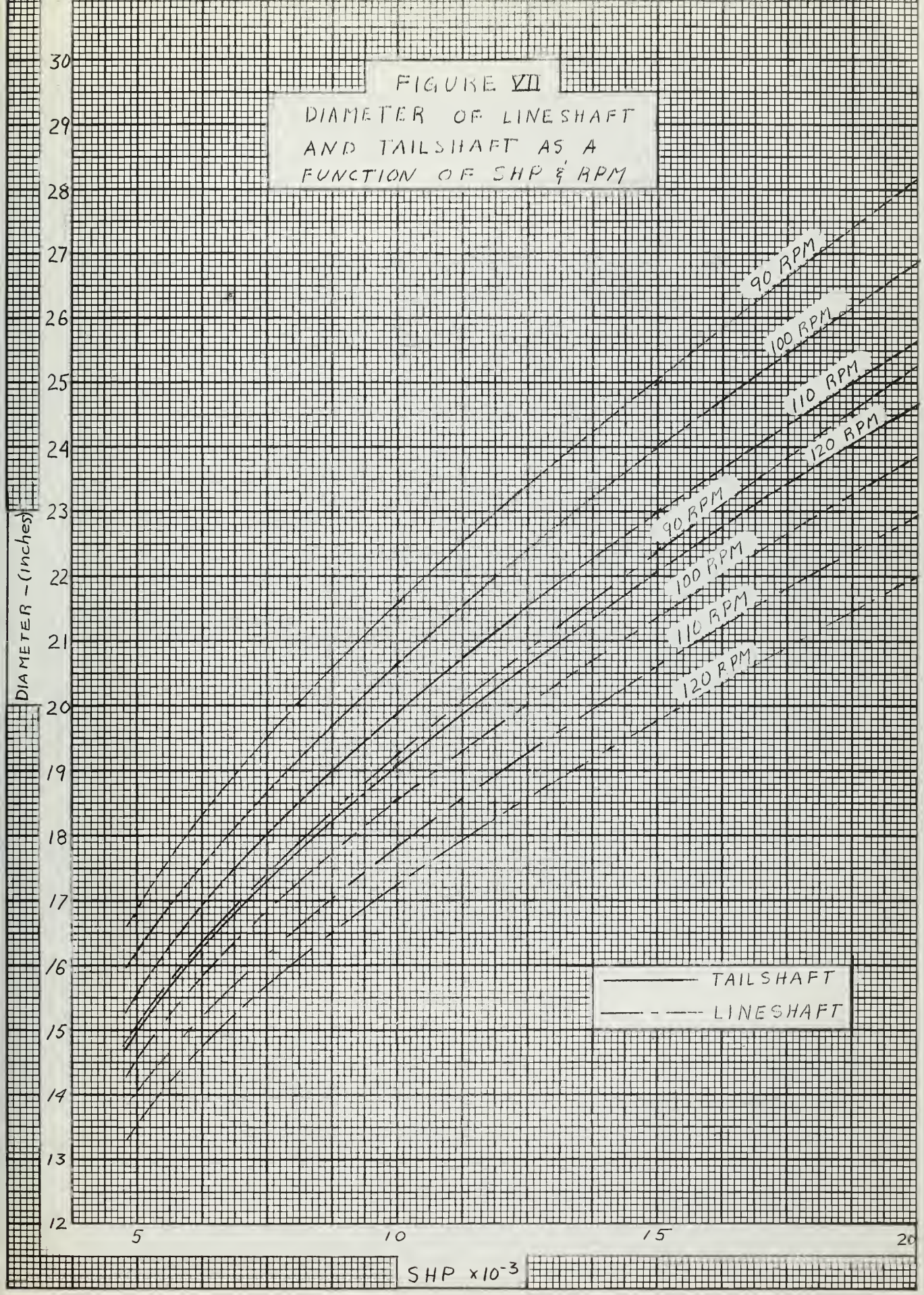
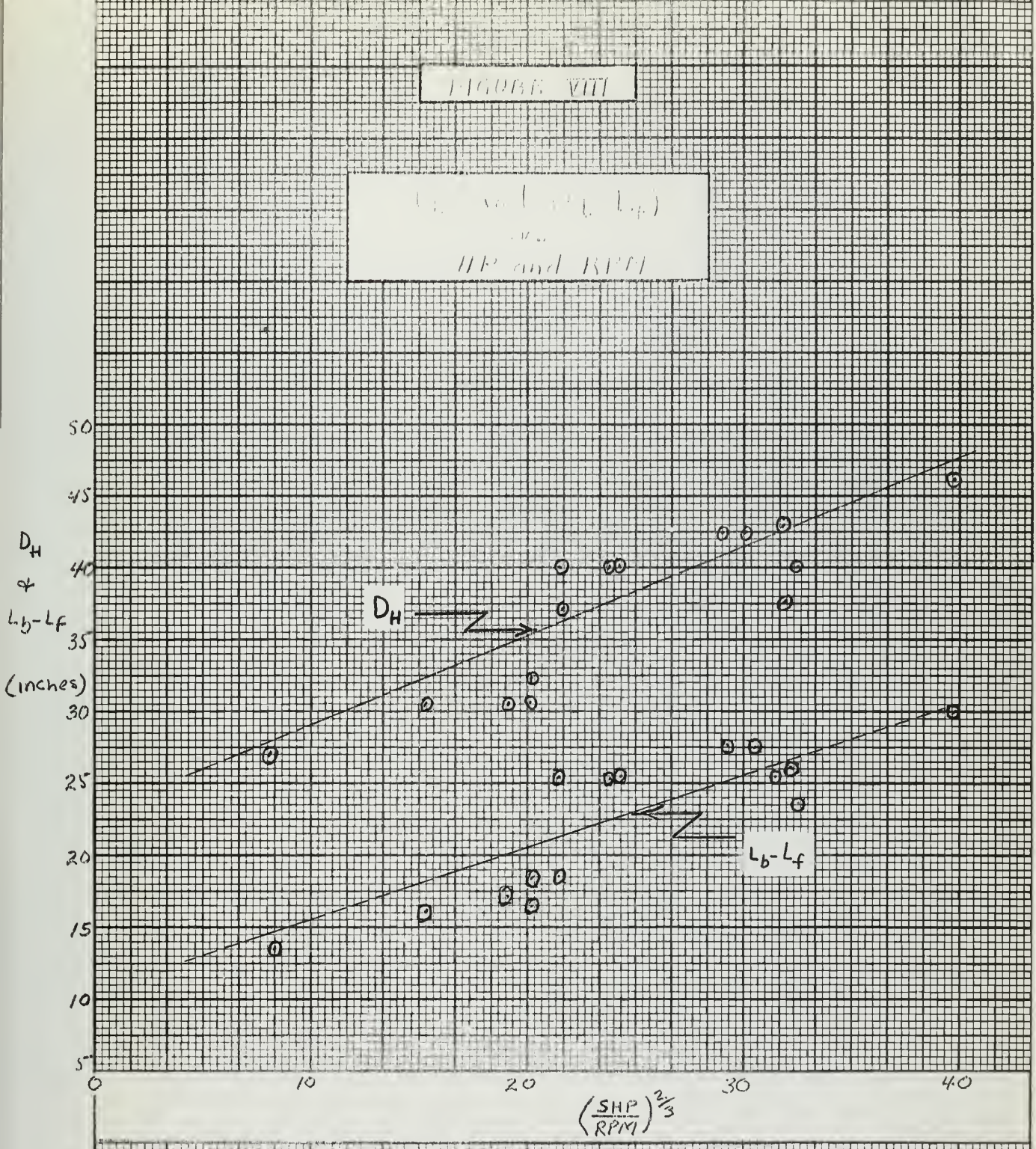


FIGURE VII
DIAMETER OF LINESHAFT AND TAILSHAFT AS A FUNCTION OF SHP & RPM
DIAMETER - (inches)
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
90 RPM
100 RPM
110 RPM
120 RPM
90 RPM
100 RPM
110 RPM
120 RPM
TAILSHAFT
LINESHAFT
5
10
15
20
SHP x10-3

FIGURE VIII

(D_H and $L_b - L_f$)
vs.
HP and RPM

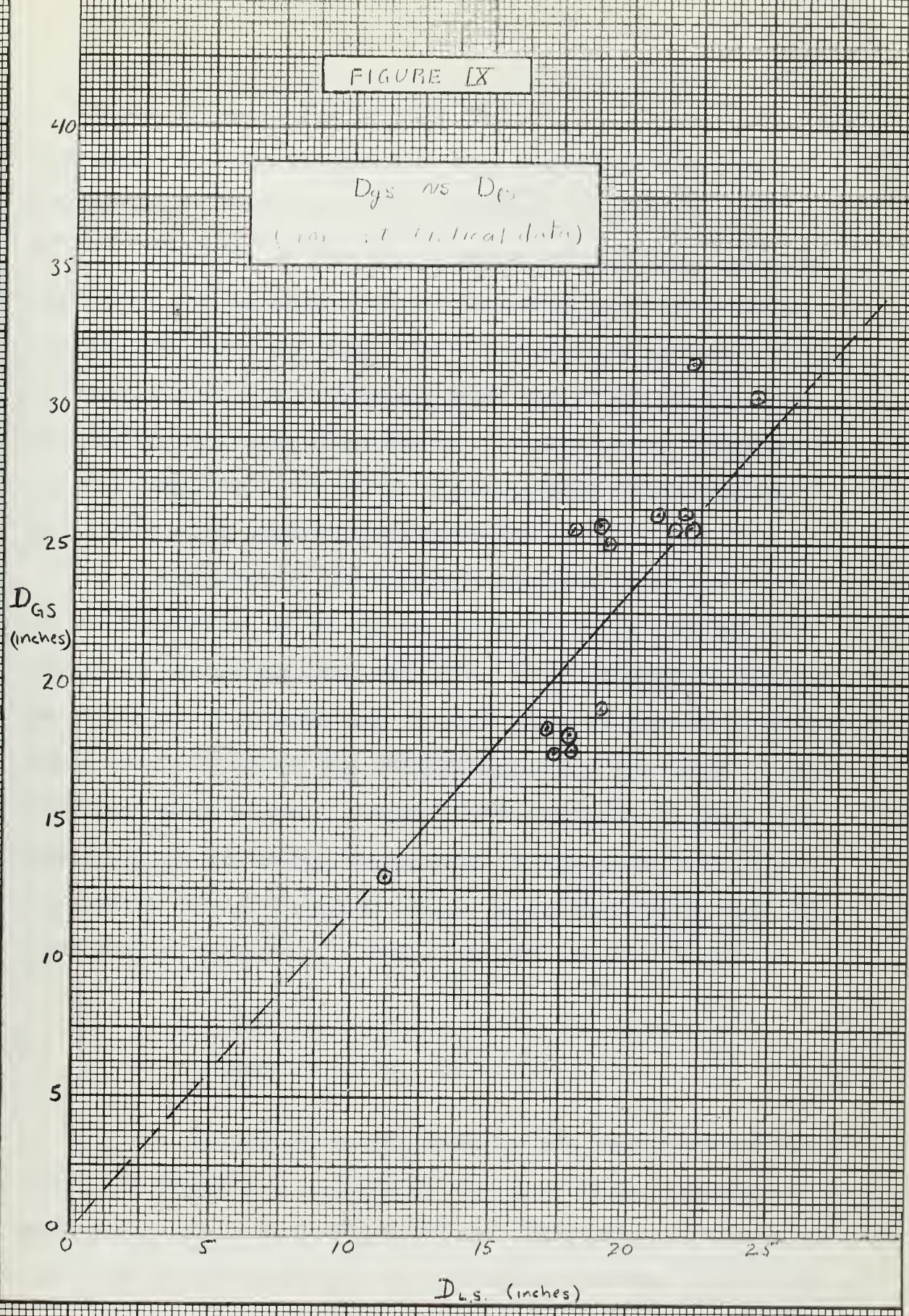


3/15/80 WOO

FIGURE IX

D_{GS} vs $D_{L.S.}$

(for [illegible] actual data)



3/6/60 WDM

satisfies the requirements of the representative system. The merchant ship class was selected.

Because of the large number of factors involved with each of the variables which depend upon designer's choice, recourse was taken to a statistical approach. The statistical data was compiled from the files of the Lynn Gear Works, General Electric Co., Boston Naval Shipyard, and the Department of Naval Architecture, Massachusetts Institute of Technology (Appendix "D").

Analysis of the statistical data permitted many of the variables to be expressed in terms of the two independent variables, SHP and RPM. Where possible, direct calculations were made and checked against the statistical data; in other cases the statistical data was used to perform the calculation. The detailed analysis of data and reduction of variables is covered in Appendix "C". The results of the analysis as shown in Figures II through IX, permitted a reduction to the five independent variables:

1. SHP	3. L_n	5. L_1
2. RPM	4. L	

It should be noted, that in the reduction of the lineshaft diameter, a decision was made which imposes an additional limit upon the problem. Through use of the combined stress equation, the lineshaft bending stress, M_b,

and the maximum allowable bearing spacing are directly related. A preliminary survey of typical shaft system solutions made available at the Lynn Gear Works, General Electric Co., indicated that, with bearing spacings currently in use, the maximum bending moment in the lineshaft was very low compared to that at the after stern tube bearing. It was, therefore, decided that a more uniform picture of bending moment would be provided by setting the maximum lineshaft bending moment equal to the maximum tailshaft moment, $W_p L_p$. This requires that, in the analysis of the results, the lineshaft bending moment shall not exceed $W_p L_p$ <u>after</u> the shaft has been given a "minimum alignment".

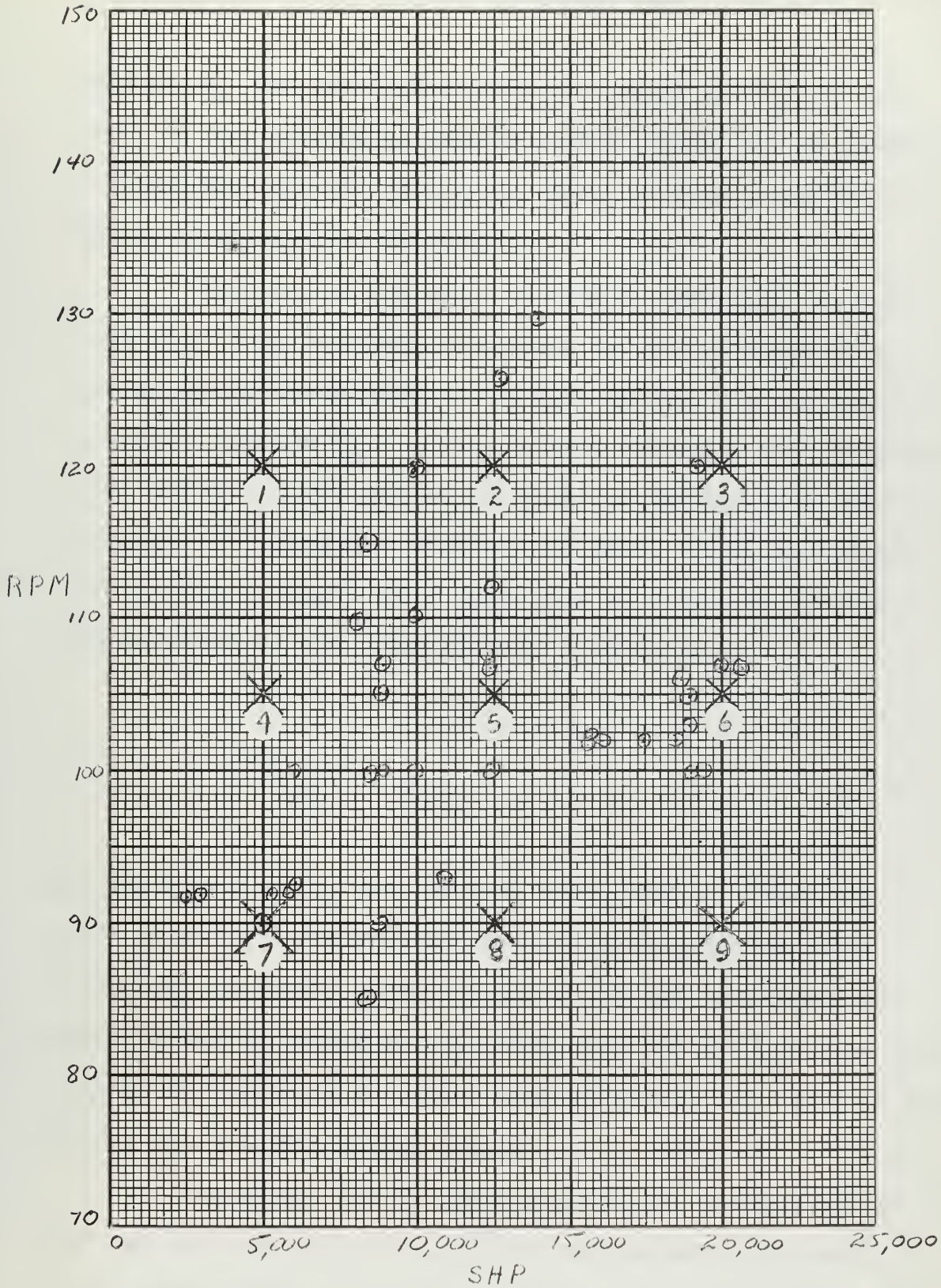
3. Development of the Family

The range of SHP and RPM used in the development of the family of representative systems is based on a plot of SHP and RPM (Figure X) for the class ship under consideration. Nine systems were chosen for analysis which effectively cover the entire operating range. The values of SHP and RPM were then used to determine the required dependent dimensions and loadings of each system.

L and L_n for each system

By varying L_n, M_b (the bending moment) is changed.

FIGURE X



STATISTICAL RANGE
OF SHP & RPM

However, M_b has previously been set equal to $W_p L_p$. This, then, is the maximum allowable moment which may be permitted to occur through the variation of L_n without reducing the factor of safety for the shaft.

Because of the gear alignment criteria, it was known that some vertical alignment of the straight line beam solution would have to be made which, for any specific L_n would increase M_b. A preliminary analysis was therefore made, using a shaft system selected at random (G-2 Series, Appendix "F") from the statistical data, which indicated that in the straight line condition M_b could be closely approximated by the clamped beam relationship

$$\frac{W_{\ell s} L_n^2}{12} = W_p L_p \qquad (6)$$

and in this case L_n was defined as L_n(max.). When the first lineshaft bearing was raised to balance the gear loads, M_b increased quite rapidly. It was therefore decided to set L_n equal to 70%, 80%, and 90% of L_n(max.) and compare the maximum adjusted bending moment for each of these values against the design moment.

Using the family characteristics, determined by SHP and RPM, and L_n(max.), it was determined that the natural frequency of the lineshaft, reduced 60% for support

elasticity, was very near to critical. However, recalling that the frequency is approximately inversely proportional to L_n^2, there is no reason to suspect that 90% of L_n(max.) will be a critical length.

By varying L_n, L will also change for a given number of bearings. The total length of the shaft system for merchant ships varies from a minimum of about 60 feet for machinery aft to a maximum of about 200 feet for machinery amidships. On this basis, it was determined that, by using one, two, and three lineshaft spans for each value of L_n, the usual range of L was covered.

The result of using three values of L and L_n for each of the systems established by SHP and RPM increased the number of systems requiring solution and analysis to eighty-one.

L_1 for each system

The length between the last two bearings (L_1) is largely determined by the length of stern tube which may be used within the physical dimensions of the ship, and by a consideration of the lateral frequency of vibration. Evaluation of the lateral frequency for the tailshaft area indicated that L_1 could be any reasonable value for the size ship associated with the SHP and RPM of the particular family. L_1 was therefore fixed for each of the families at a value given by:

$$L_1 = .5 \sqrt{\frac{W_p \quad L_p \quad 12}{W_{ts}}} \qquad (7)$$

Family number 5 was also analyzed for

$$L_1 = .7 \sqrt{\frac{W_p \quad L_p \quad 12}{W_{ts}}} \qquad (8)$$

so as to have an indication of the effect of varying this dimension on the overall system. These two values of L_1 encompass the range that one might expect would be required by the geometry of the ship.

The final nine families, as described in Table I, and their associated systems with variables L_n and L, were then prepared for computer solution of bending moment, shear, deflection, slope, bearing reaction, and reaction influence numbers. They were assigned reference numbers as per the example below

S	-	1	-	90		3
Series		Family		90% L_n (max.)		three line shaft spans

Where reference is made to S-1-003 the meaning is "all values of L_n for 3 spans".

The computer solutions for S-5-001, S-5-002, and S-5-003 are shown in Appendix "F". In all but a few specific cases, family 5 was used for sample calculations.

4. Analysis of Computer Solutions

The basic computer solution is for the shaft aligned in the straight line condition. In all cases, as predicted, the aft reduction gear bearing was very heavily loaded and the forward one lightly or negatively loaded. It was decided that, for purposes of uniformity, the reduction gear bearing loads, R_1 and R_2, should be made equal. This was accomplished through use of the "minimum alignment criteria" in the sense that only the No. 3 bearing (first lineshaft bearing) was aligned vertically. Such was accomplished through use of the reaction influence numbers of No. 3 bearing. By making use of the change in reaction at each bearing, the change in shear was computed. Then by stepwise integration over the length of the system the change in bending moment at any location could be obtained. Adding the original moment, M_o, the moment is found for any station in the aligned condition. It should be noted that in the "minimum aligned" condition the maximum moment occurred at bearing No. 3. For bearing No. 3 we may then say

$$M_3 = M_o + \int_o^{\ell_1} \Delta R_1 \, d\ell + \int_{\ell_1}^{\ell_2} (\Delta R_1 + \Delta R_2) d\ell \qquad (9)$$

This value of M_3 was then plotted against percent L_n(max.) so that, for example, systems S-5-901, 801, and 701 could be used to plot a fair curve. The intercept of this curve with the design moment then indicated the maximum value of L_n which could be used for family 5 with one lineshaft span. The plots indicated that $M_b = M_o$ (max.) allowable at some value less than 70% L_n(max.), hence additional problems using 2 spans, were run for each system using 60% L_n(max.). These runs definitely established the percent L_n(max.) at crossover and justify extrapolation of the curves for one and three spans. Other calculations were made by a similar analysis, to show the effect of reduction gear settlement, stern tube wear down and variation of L_1, ΔW_g, W_p, and L_b.

Similar calculations were made for S-5-801A using minimum alignment and an overall alignment to indicate the method by which M_3 may be reduced so as to realize a higher value of L_n. The overall alignment is performed by trial and error until the desired condition is obtained. Skill in the use of this method is attained only through practice and was not considered practical for use with all of the systems.

Once the shaft had been aligned and the new bearing reactions obtained, a check was made to insure that the prescribed bearing pressure of 100 psi had not been exceeded. This calculation was based on the use of a bearing L/D of 1.5.

TABLE I

Characteristics of the Families

Family	1	2	3	4	5
SHP	5,000	12,500	20,000	5,000	12,500
RPM	120	120	120	105	105
W_p	20,900	43,600	64,900	23,500	51,200
W_p *	18,130	37,800	56,300	20,400	44,400
D_{ts}	14.98	20.72	24.68	15.81	22.01
W_{ts}	50.00	95.25	135.25	55.50	107.50
D_{ls}	13.51	18.68	22.03	14.27	19.67
W_{ls}	40.45	77.50	107.70	45.20	85.80
L_p	31.45	43.50	51.85	33.20	46.20
L_f	30.50	39.00	44.50	31.70	40.50
$L_b - L_f$	16.50	21.50	25.60	17.20	22.80
L_b	47.00	60.50	70.10	48.90	63.30
D_h	30.20	36.50	41.60	30.80	37.80
Dgs	15.68	21.65	25.55	16.54	22.80
Wg	18,100	44,700	65,300	21,800	49,800
Wg (equiv)	7,102	13,825	20,870	7,750	15,520
ΔWg	10,998	30,875	44,430	14,050	34,280
M_{b_2} (Kip-in)	657	1,897	3,365	780	2,365
Wr^2 (10^{-6})	29.5	91.0	160.5	40.5	124.5
L_n (max)	442	542	612	455	575
L_l (max)	398	490	546	411	514
50% L_l (max)	199	245	273	206	257
70% L_l (max)	278	343	382	287	360
90% L_n (max)	398.0	488.0	551.0	409.5	517.5
80% L_n (max)	353.0	434.0	490.0	364.0	460.0
70% L_n (max)	309.0	379.0	428.0	318.5	402.5
60% L_n (max)	265	325	367.0	273.0	345.0

TABLE I (con'd)

Family	6	7	8	9
SHP	20,000	5,000	12,500	20,000
RPM	105	90	90	90
W_p	77,300	28,300	60,000	90,400
W_p *	67,100	24,550	52,100	78,400
D_{ts}	26.27	16.78	23.43	28.10
W_{ts}	153.00	62.55	122.00	175.50
D_{ls}	23.42	15.11	20.92	24.93
W_{ls}	121.70	50.60	97.10	138.00
L_p	55.20	35.20	49.30	59.00
L_f	46.25	32.85	42.30	48.30
$L_b - L_f$	27.00	17.70	23.80	28.70
L_b	73.25	50.55	66.10	77.00
Dh	43.30	31.80	39.50	45.50
Dgs	27.05	17.55	24.25	28.90
Wg	72,300	25,600	56,700	81,100
Wg (equiv)	23,650	8,587	17,760	27,560
ΔWg	48,650	17,013	38,940	53,540
M_{b_2} (Kip-in)	4,267	996	2,958	5,334
Wr^2 (10^{-6})	226.0	56.5	175.0	320.0
L_n (max)	649	486	604	680
L_1 (max)	578	436	538	604
50% L_1 (max)	289	218	269	302
70% L_1 (max)	405	302	376	422
90% L_n (max)	584.0	437.4	544.0	612.0
80% L_n (max)	519.0	388.8	483.0	544.0
70% L_n (max)	454.0	340.2	423.0	476.0
60% L_n (max)	389.0	292.0	362.0	408.0

TABLE II

Natural Frequency of Lineshaft
(reduced 60% for bearing elasticity)

Family	RPM	L_n^f(max)	90% L_n^f(max)	80% L_n^f(max)	70% L_n^f(max)
1	120	131*	162	204	267
2	120	119*	147	186	243
3	120	111*	137*	173	226
4	105	129	159	202	263
5	105	112*	140	177	230
6	105	106*	131	166	216
7	90	121	149	189	247
8	90	108	133	169	220
9	90	101*	125	158	206

*Calculated value less than 115% RPM.

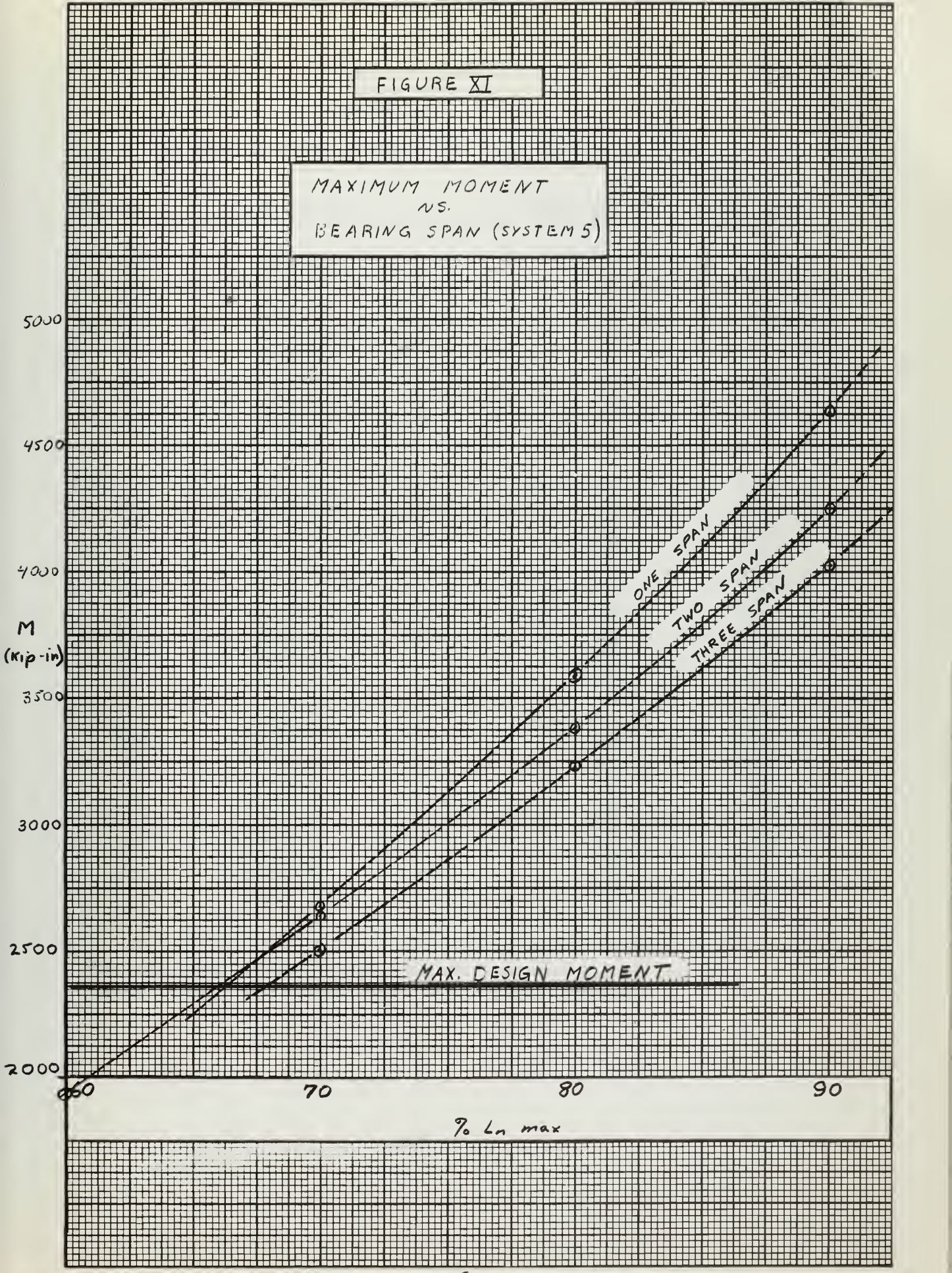
TABLE III

Natural Frequency of Tailshaft

Family	RPM	L_1^f(max)	70% L_1^f(max)	50% L_1^f(max)
1	120	287	466	660
2	120	190	409	598
3	120	138*	382	572
4	105	313	481	636
5	105	223	410	570
6	105	178	376	538
7	90	316	458	595
8	90	232	386	542
9	90	210	378	517

* Calculated value less than 115% RPM.

FIGURE XI



4/22/60 RM

TABLE IV

Maximum Bending Moment for the Systems*

System	M (max)	System	M (max)
S-1-701	728.0	S-4-701	867.5
801	975.7	801	1165.5
901	1270.5	901	1508.0
602	543.0	602	644.3
702	726.5	702	863.1
802	942.9	802	1113.4
902	1179.4	902	1396.1
703	692.1	703	821.4
803	890.9	803	1028.2
903	1128.0	903	1337.6
S-2-701	2107.0	S-5-701	2674.9
801	2850.7	801	3594.6
901	3671.4	901	4635.7
602	1570.5	602	1909.0
702	2101.2	702	2649.9
802	2719.1	802	3384.9
902	3400.6	902	4246.6
703	2002.7	703	2506.2
803	2596.9	803	3233.2
903	3254.5	903	4020.6
S-3-701	3795.9	S-6-701	4847.7
801	5111.8	801	6471.2
901	6593.0	901	8360.4
602	2791.8	602	3612.5
702	3727.3	702	4741.1
802	4839.4	802	6116.7
902	6029.8	902	7577.7
703	3562.8	703	4518.3
803	4617.2	803	5845.1
903	5783.6	903	7330.4

* The maximum moment occurred at bearing No. 3 in all cases under the alignment conditions imposed.

TABLE IV (con'd)

System	M (max)	System	M (max)
S-7-701	1104.7	S-5-701A	2521.2
801	1484.3	801A	3341.6
901	1919.6	901A	4294.4
602	822.7		
702	1100.3	702A	2567.0
802	1418.7	802A	3338.0
902	1777.5	902A	4198.9
703	1048.5	703A	2506.0
803	1355.9	803A	3235.6
903	1700.2	903A	4056.7
S-8-701	3326.5	S-6-701	4772.4
801	4452.7	801A	6404.3
901	5764.8	901A	8252.1
602	2439.6		
702	3275.8	702A	4697.0
802	4217.8	802A	6062.7
902	5298.7	902A	7601.3
703	3080.2	703A	4476.6
803	4027.4	803A	5787.2
903	5064.3	903A	7269.1
S-9-701	6039.6		
801	8108.9		
901	10441.6		
602	4411.2		
702	5905.4		
802	7616.9		
902	9545.1		
703	5629.8		
803	7274.6		
903	9130.7		

FIGURE XII

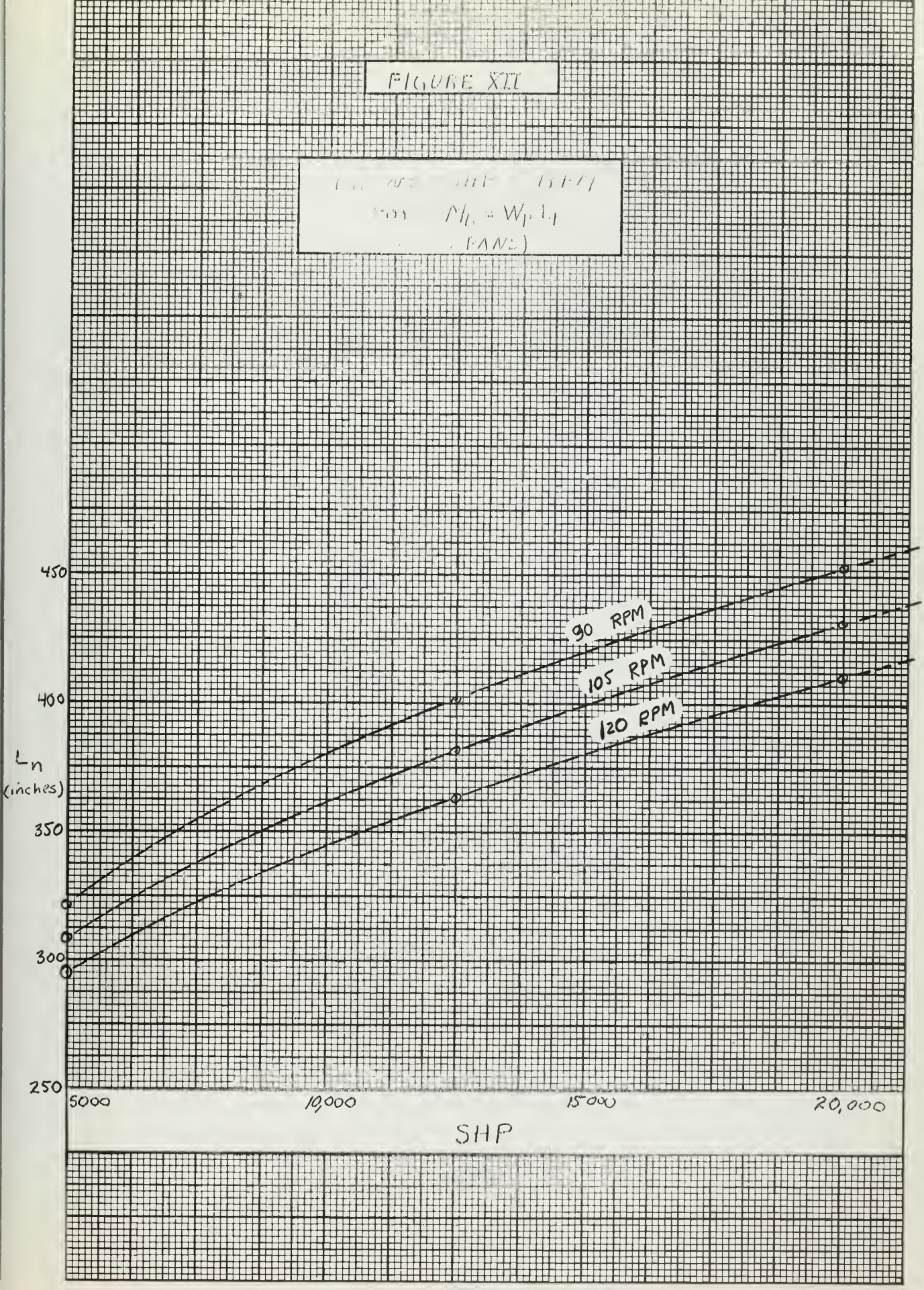


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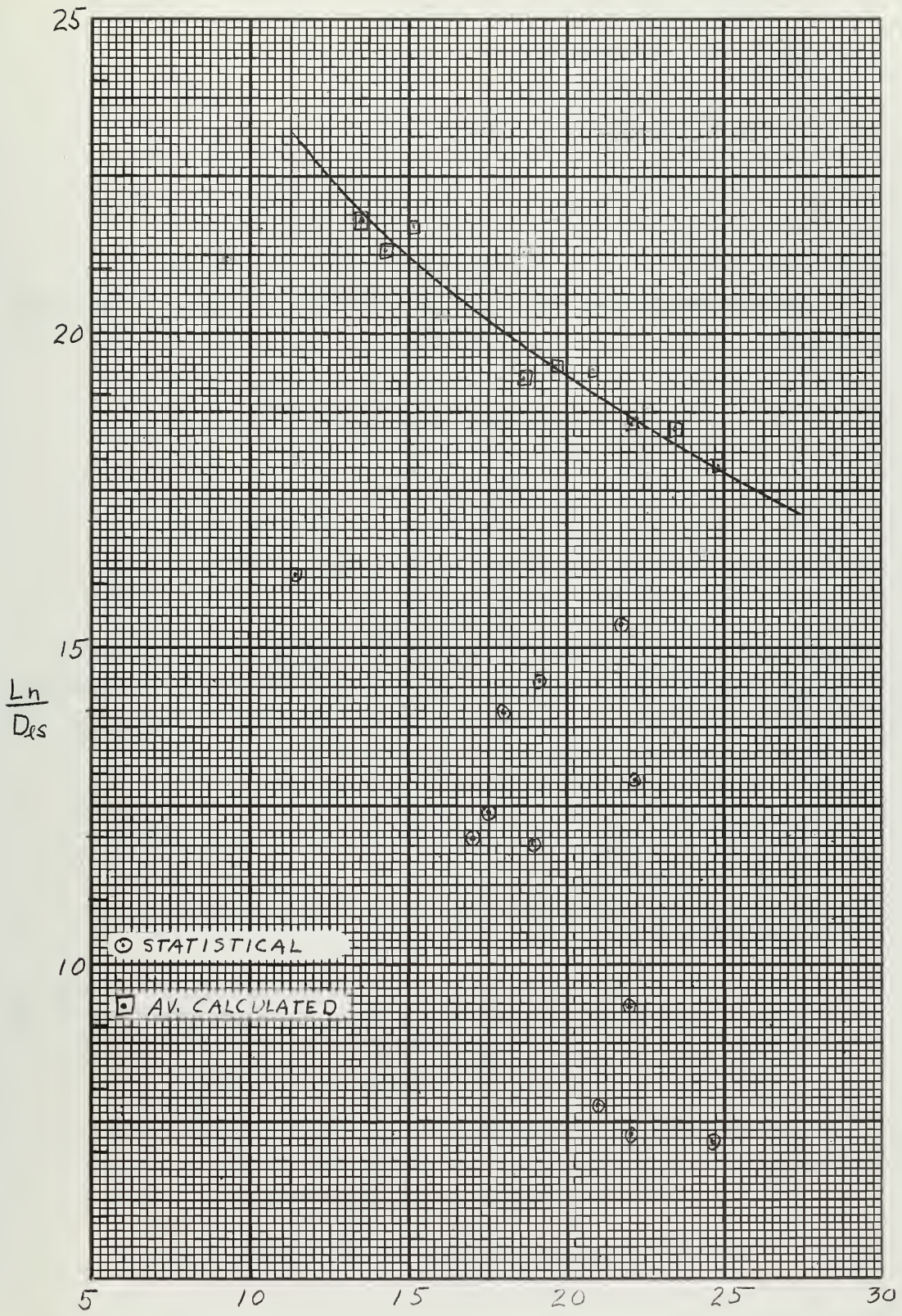
TABLE V

Limiting Percent L_n(max), Allowable L_n and L_n/D_{ls} Ratio of the Lineshaft Span

System	% L_n(max)	L_n	L_n/D_{ls}
S-1-001	67.0	296.14	21.8
002	66.4	293.49	21.6
003	68.0	300.56	22.1
S-2-001	66.9	362.60	19.2
002	66.5	360.43	19.3
003	67.8	367.48	19.5
S-3-001	66.8	408.81	18.5
002	66.8	408.81	18.5
003	68.0	416.16	18.8
S-4-001	66.9	304.39	21.2
002	66.7	303.48	21.2
003	67.8	308.49	21.6
S-5-001	66.6	382.95	19.4
002	66.0	379.50	19.3
003	67.8	389.85	19.7
S-6-001	66.2	429.63	18.3
002	66.4	430.93	18.4
003	67.7	439.37	18.7
S-7-001	66.3	322.22	21.7
002	66.0	320.76	21.6
003	67.8	329.51	22.1
S-8-001	66.5	401.66	19.2
002	66.5	401.66	19.2
003	68.5	413.74	19.7
S-9-001	66.7	453.56	17.9
002	66.4	450.84	17.7
003	68.0	462.40	18.1

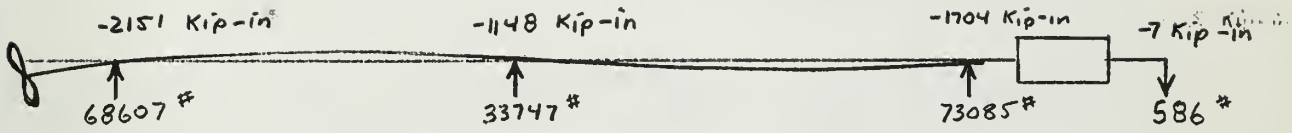
FIGURE XIII



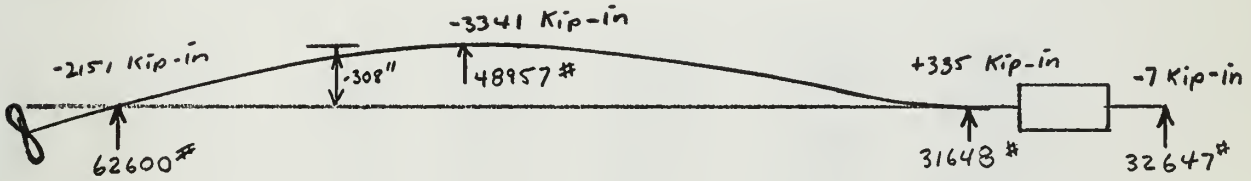
COMPARISON OF STATISTICAL AND CALCULATED L_n/D_{es} RATIO

FIGURE XIV

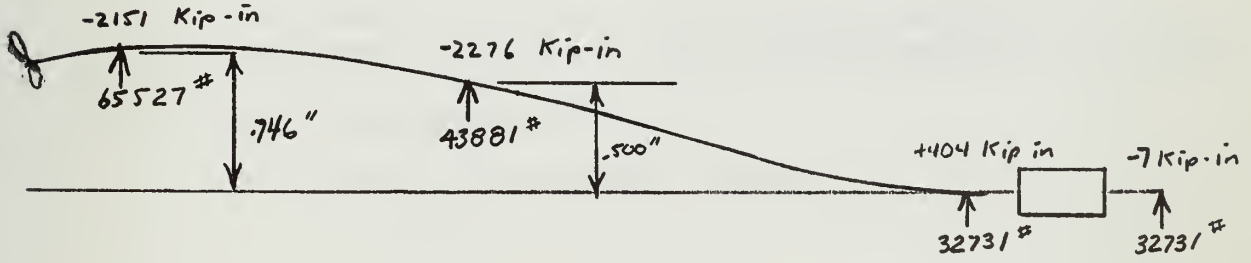
COMPARATIVE ALIGNMENTS (S-5 801A)



CASE I - STRAIGHT LINE



CASE II - MINIMUM ALIGNMENT



CASE III - IMPROVED ALIGNMENT

TABLE VI

Effect of Stern Tube Wear and Reduction Gear Settlement for Odd and Even Number of Bearings

S-5-801A	Bearings 1	2	3	4	5
R* - in line	-586	73085	33747	68607	-
R - aligned(1)	31647	31648	48957	62600	-
M - aligned	-7.5	+335.7	-3341.6	-2151.3	-
R-gear cold(2)	33230	29679	49554	62388	-
M-gear cold	-7.5	+435.9	-3419.0	-2151.3	-
R-wear down(3)	38799	21793	53822	60432	-
M-wear down	-7.5	+788.4	-4132.3	-2151.3	-
S-5-802A					
R - in line	3178	67763	40957	34058	68534
R - aligned	31644	31645	55053	24202	71947
M - aligned	-7.5	+335.7	-3338.2	+72.7	-2151.7
R - gear cold	33084	29873	55553	23974	72002
M - gear cold	-7.5	+426.9	-3399.7	+88.5	-2151.7
R - wear down	31621	31951	53113	27605	70204
M - wear down	-7.5	+2431	-3147.9	-576.5	-2151.7

Note: (1) aligned refers to minimum aligned condition.

(2) gear cold refers to 0.020 inch settlement of reduction gear from aligned condition.

(3) wear down refers to 0.219 inch weardown of stern tube in the hot aligned condition, (BSM-43)

* R - bearing reaction, lb.

\+ M - moment at bearings, Kip-in.

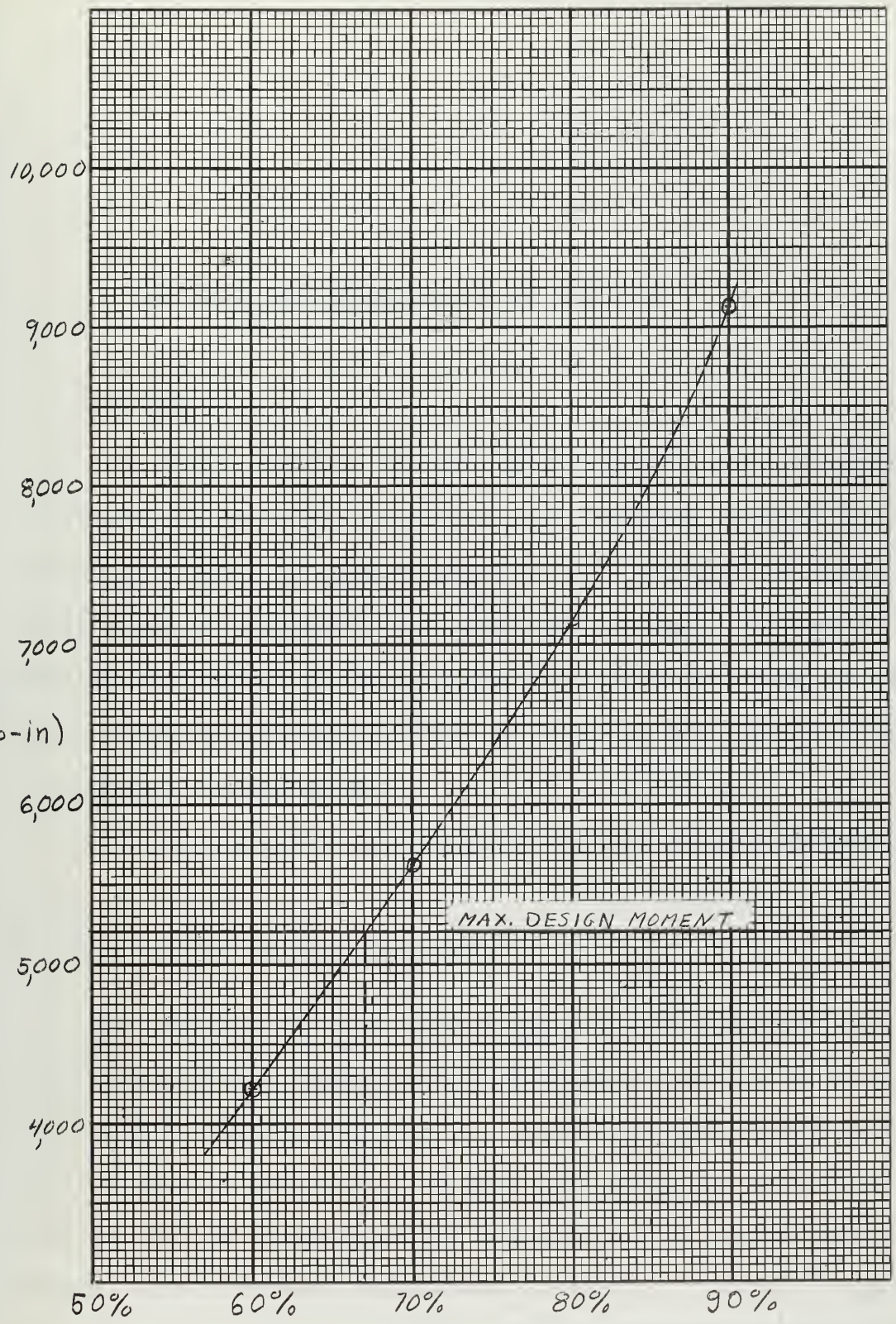
TABLE VII

Maximum Lineshaft Bearing Pressures

System	Maximum Reaction	$D_{L.S.}$	P(psi)*
S-1-701	14121	13.51	51.5
S-1-702	17845	"	65.0
S-1-703	16870	"	61.5
S-2-701	33285	18.68	63.5
S-2-702	41757	"	79.8
S-2-703	39654	"	75.9
S-3-701	52753	22.03	72.3
S-3-702	65760	"	90.1
S-3-703	62364	"	85.4
S-4-701	16119	14.27	52.8
S-4-702	20436	"	67.0
S-4-703	19450	"	63.7
S-5-701	39258	19.67	67.5
S-5-702	49076	"	84.5
S-5-703	46681	"	80.2
S-6-701	63373	23.42	77.0
S-6-702	78781	"	95.7
S-6-703	74653	"	90.8
S-7-701	19401	15.11	56.6
S-7-702	24546	"	71.6
S-7-703	23241	"	67.9
S-8-701	46763	20.92	71.0
S-8-702	58509	"	89.0
S-8-703	55398	"	84.2
S-9-701	75489	24.93	81.0
S-9-702	93663	"	100.0+
S-9-703	88887	"	95.2

* Bearing L/D ratio assumed at 1.5.

FIGURE XV



MAXIMUM MOMENT vs. BEARING SPAN

SYSTEM #5 - SPECIAL

IV.

RESULTS AND DISCUSSION OF RESULTS

1. Results

The major results of the investigation are presented here in graphical and tabular form. All results, except those for system S-5-SPECIAL, are subject to the previously imposed conditions of alignment and combined stress. System S-5-SPECIAL was based on an arbitrarily selected value of line-shaft bending moment in order to explore the possible effect of geometric similarity.

Data and sample calculations appear in the appendices.

2. Discussion of the Results

The results of this investigation, as compared to statistical data, (Fig. XIII), indicate that it is feasible to increase lineshaft spans at least 25% over those used in current design practice. Within the range of variables covered by the investigation and subject to the stated assumptions, the most important limitation is that imposed by the maximum bending moment occurring in the lineshaft span (Table IV). It is possible that with other ranges of

SHP and RPM the limitations of increased bearing pressures, critical natural frequency and buckling stability may be important considerations.

The analysis of the nine families indicated that the maximum allowable L_n was, for all the systems, approximately equal to 67% of L_n (max.), (Table V), where L_n (max.) is defined by equation (6). Further, this allowable L_n was $\approx 20\ D_{\ell s}$, slightly greater for low (5000) SHP and slightly less for high (20,000) SHP.

That these findings are not a result of investigating geometrically similar shaft systems will be explained in detail (Variation of Parameters), but they are dependent upon the imposed alignment criteria. Since the "minimum alignment criteria" adopted for this investigation tends to reduce the allowable L_n, it can be presumed that greater lineshaft bearing spacing than that indicated in this investigation is possible, subject to some limitation other than shaft stress. Consequently, these results can certainly be used in the preliminary design stage, and can be revised subject to further analysis of the particular system being considered.

It is suggested that further investigation be conducted to determine the effect of unequal lineshaft bearing spans and that a computer program be devised which will determine the optimum spacing subject to criteria of gear alignment,

bearing pressures, buckling stability, and natural frequency. Such a program could be used to develop a set of design charts or could be made general enough to be used for the complete design of individual systems.

Effects of Lateral Frequency Limitation

The lateral critical frequency of vibration was calculated for both lineshaft and tailshaft (Tables II and III). The results of this calculation show that for the geometries and RPM involved, there is little possibility of tailshaft vibration, but the lineshaft approaches the critical range. It is recommended that further investigation of this limitation be made, with the lineshaft designed for a higher M_b, varying the lineshaft diameter only, until the lineshaft critical frequency is a limiting criteria.

It is also recommended that future studies be made for those shaft systems operating at high RPM, where this limiting criteria takes on greater importance.

Effect of Bearing Pressure Limitation

As a possible limitation on increased bearing span, the bearing pressures are the most controversial. Since the maximum L_n occurred at approximately 67% L_n (max.), the bearing pressures were calculated from the nearest set of reactions

available, which was the 70% series. The maximum load on the lineshaft bearings after "minimum alignment" occurred at the first lineshaft (No. 3) bearing, and the resulting pressures based on an $L/D_{\ell_s} = 1.5$, are shown in Table VII. The stern tube bearing was not considered in this calculation, since the length of this water lubricated bearing will be several diameters long. Also, the majority of the load on this bearing is due to the propeller overhang and only slightly changed by the concepts used in this investigation. The table indicates that for the allowable L_n resulting from this investigation, the maximum bearing pressures are greater than present practice indicates, but in no case would they exceed 100 psi, when corrected to the 67% L_n (max.) case. Referring to Figure XIV, it can be seen that the improved alignment will reduce the load (bearing pressure) on No. 3 bearing. In addition, the shaft will have a bearing journal sleeve installed, so that for a given bearing L/D ratio, the total bearing area will be greater, further reducing the pressure. It is felt, that in view of the above arguments, the higher pressures calculated be considered acceptable.

It can also be noted from Table VII that the maximum bearing pressure occurred for the two span systems. This is due to the influence of the propeller weight. For the one lineshaft span system, the propeller tends to unload No. 3 bearing, but for the two lineshaft span system, the pro-

peller tends to load the No. 3 bearing. For the three line-shaft span system, the effect of the propeller is negligible.

Variation of Parameters

Because of the large number of problems required for solution, no deliberate attempt was made to determine the effect of variation of parameters on the shaft system. The one exception, that of varying lineshaft diameter, will be explained in detail.

However, because of errors in setting up the problems, and errors in card punching, many of the parameters were changed. Comparisons were made where possible, and are discussed individually.

It is recommended that further investigation of the effects of varying each parameter be made, since the system may be sensitive to changes in certain of these parameters.

The length of the span between gear bearings was varied 14% for the complete family No. 6. The results of this variation are shown in Table VIII. The variation of the span resulted in a negligible change in the per cent of L_n (max.) at which the design moment was realized. It is therefore concluded that, as all the systems had approximately the same limiting per cent L_n (max.) in the initial condition, all the systems will behave similarly to system No. 6 for variations in gear bearing spacing.

TABLE VIII

Effect of Variation of Gear Bearing Span

Number of Spans	S-6-000 L_b = 73.25" ($\%L_n$ (max.))	S-6-000A L_b = 63.24" ($\%L_n$ (max.))
1	66.2	66.7
2	66.4	66.4
3	67.7	68.2

The complete family No. 5 was computed using two values of L_1 as defined by equations (7) and (8). As shown in Table IX, a 40% increase in L_1 over that used in the original nine families resulted in a negligible change in the allowable per cent of L_n (max.). As above, it may therefore be concluded that variation of L_1 will have negligible effect upon all of the families.

TABLE IX

Effect of Variation of Tailshaft Span

Number of Spans	S-5-000 L_1 = 50% L_1 (max.) ($\%L_n$ (max.))	S-5-000A L_1 = 70% L_1 (max.) ($\%L_n$ (max.))
1	66.6	67.8
2	66.0	67.2
3	67.8	67.8

The effect of variation of propeller weight was considered using systems S-9-801 and S-9-801A. The propeller weight was reduced from 78,400 to 28,400 pounds in problem S-9-801A. With the exception of reduced reactions in the vicinity of the propeller, no major changes in the behavior of the system were noted. In the aligned condition the maximum lineshaft moments were:

S-9-801 (W_p = 78,400 lb) ..... M(max) = 8108.9 kip-in
S-9-801A (W_p = 28,400 lb) ..... M(max) = 8266.4 kip-in

Inasmuch as the effect of propeller overhang is most serious in systems with very short overall length, it is logical to conclude that the propeller weight has an insignificant effect on the alignment behavior of the shaft system.

The effect of varying the concentrated gear weight can be seen from problems S-1-702 and S-1-702A. The gear weight was omitted entirely in S-1-702A. As with the propeller weight, the only effect was a change in the reactions in the vicinity of the gear. The maximum lineshaft moments in the aligned condition were:

S-1-702 (ΔW_g = 10,998 lb) ..... M(max) = 726.5 Kip-in
S-1-702A (ΔW_g = 0) ..... M(max) = 725.4 Kip-in

Because of the similar behavior of the original systems, it is concluded that variation in gear weight will have no effect upon the lineshaft stress in the aligned condition.

The total length of the system was varied by changing the number of spans. From Table IV it is seen that this caused a negligible effect on the crossover point, the effect resulting in a maximum change in allowable L_n of 1 to 2 per cent.

It is noted that for values of L_n greater than L_n (max.), the maximum lineshaft bending moment decreased with increased total length (increased number of spans).

The variation of the line shaft diameter was not contemplated until the analysis of the family of systems originally chosen was completed. Since the 67% L_n (max.) value was a consistent limitation for all nine of the families investigated, the possibility existed that nine similar families had resulted through the use of M_b (max.) $= W_p L_p$ and the combined stress equation by which the shaft diameter was calculated.

This possibility of similarity was eliminated by assuming an arbitrary M_b not equal to $W_p L_p$ and calculating D_{ls} by combined stress. This was done for family No. 5, (S-5-SP602, S-5-SP702, and S-5-SP902). The results are shown in Figure XV. Although similarity was eliminated, the resulting allowable L_n was 67% of L_n (max.).

Because of this result, and the results of varying the other parameters previously discussed, it is concluded that as long as the lineshaft diameter is calculated on the basis of some allowable M_b, and this M_b is not exceeded in the final

aligned condition, the allowable L_n will be some constant percentage of L_n (max.). The exact percentage will depend upon the alignment criteria adopted by the designer.

Effect of Alignment Criteria

By using the minimum alignment criteria outlined in the procedure, certain phenomena were found to exist. The maximum lineshaft bending moment and maximum lineshaft bearing reaction occurred at No. 3 bearing. In performing the vertical alignment, the changes in moments and reactions were calculated expediently by means of a desk calculator. This method is recommended in lieu of a second computer solution as more rapid and less costly to perform. However, the required accuracy (no closure error) of the calculations can only be obtained if the RIN are given to two decimal accuracy (one hundredth of a pound change per mil of bearing rise). It is recommended that the computer output be modified to give this required accuracy in the RIN. At present a "dump" must be used.

To illustrate the beneficial effect of performing more than a "minimum alignment", modified calculations for S-5-801A were made, and are illustrated in Figure XIV. It can be seen from the figure, that in the straight line condition (Case I) there is a serious differential in gear bearing reactions which will result in misalignment of the

gear. By performing the "minimum alignment", (Case II), the requirements of the gear manufacturer are met, but a large maximum lineshaft bending moment results. Case III illustrates how, by using "improved alignment" (adjusting more than No. 3 bearing), the gear manufacturer's requirements are satisfied and a lower maximum shaft bending moment results. Further refinement of Case III could be made, the optimum alignment occurring (in this case) when $M_3 = M_2$.

It should be noted, however, that this optimum alignment at present is a trial and error process, and increases in difficulty as the number of bearings is increased.

Effects of Gear Case Expansion and Stern Tube Weardown

These phenomena are included together because of the effect they have on the gear manufacturer's alignment criteria. Additionally, the number of bearings in the system has a major effect on the interpretation of the gear manufacturer's requirements. Two cases were used to illustrate this point; the results are given in Table VI.

Problem S-5-801A is for an even number of bearings. It can be seen that, starting from the hot aligned condition, the effect of cooling of the gear case is to increase R_1 and decrease R_2; the effect of stern tube weardown is also to

increase R_1 and decrease R_2. Since both effects tend to increase R_1 and decrease R_2, the alignment should be made so that all of the maximum allowable load differential of the gear bearings is added to the after gear bearing, R_2. Hence the alignment specification should be to make R_2 greater than R_1 by the maximum allowable load difference with the gear hot. If the alignment is made on the cold ship, the effects of gear case contraction can be taken into account so that the specifications can be met in the "hot" condition.

On the other hand, problem S-5-802A is for an odd number of bearings. Again, starting from the hot aligned condition, the effect of cooling of the gear case is to increase R_1 and decrease R_2. However, the effect of stern tube weardown is to decrease R_1 and increase R_2. Since these two conditions tend to oppose each other, an analysis of the system should be made to determine the more important effect. The specification can then be adjusted to provide the best alignment under both conditions, with more emphasis being placed on the hot aligned condition.

In conjunction with the vertical alignment, two other points should be noted; first, no limits were placed on the allowable vertical distance required for proper alignment nor were they deemed necessary. Consequently a future investigation to determine the effect of vertical alignment on buckling stability should be made. Second, the effects

of stern tube weardown on alignment should be thoroughly investigated.

Proposed Preliminary Design Method

The design, arrangement, and alignment of the system cannot be treated as separable problems. The maximum allowable lineshaft bending moment is a component of the lineshaft diameter calculation, hence it affects the design of the shaft. This moment, in addition, cannot be exceeded in the lineshaft without lowering the F.S. Consequently the bearing spacing must be limited to insure that this moment is not exceeded. However, vertical alignment to satisfy the gear manufacturer's requirements is necessary, and since this alignment will change the maximum shaft bending moment, then the design ($D_{\ell s}$), arrangement (bearing spacing) and alignment (gear bearing load) must be considered concurrently.

The authors consider the results of this investigation to be of a conservative nature, yet using "minimum alignment criteria" increases in the value of L_n of the order of 25% over current design practice appear possible. Accepting this increase in L_n, the logical approach to preliminary design of the shaft would be to obtain L_n from Figure XII. Where the desired SHP and RPM exceed the limits of this figure,

extrapolation should be possible because of the constancy of the results. Adjust L_n so that a minimum number of lineshaft spans will satisfy the total length required. Then express the lineshaft bending moment in terms of the lineshaft diameter D_{ls} such that

$$M_b = K \cdot D_{ls}^2 L_n^2 \cdot (\tfrac{\pi}{4} 0.284)$$

where $K = (\frac{1}{0.67})^2 \cdot (\frac{1}{12})$ or $\frac{3}{16}$

Substitute this moment in the combined stress equation for the lineshaft and solve for D_{ls}.

At this stage the shaft has been designed so as to satisfy combined stress in the "minimum alignment" condition. Checks should than be made to insure that other requirements (bearing load, lateral frequency and buckling stability) have not been exceeded.

It is recognized that the constant in the above equation will vary with other alignment criteria, or with other designer's limitations. However, for the purposes of preliminary design, and until other alignments are investigated, the value of the constant, K, resulting from the investigation appears reasonable.

V.

CONCLUSIONS

1. The design, arrangement and the alignment of a shaft system must be considered concurrently.

2. Within the range of SHP and RPM considered, it is feasible to increase the lineshaft bearing spacing by a minimum of 25% over current design practice.

3. As long as the lineshaft diameter is calculated on the basis of some allowable bending moment, and this bending moment is not exceeded in the final aligned condition, the maximum allowable lineshaft span will be related to the bending moment by the equation

$$M_b = K W_{ls} L_n^2$$

For the alignment criteria that reduction gear bearing reactions be made equal by vertical alignment of the first lineshaft bearing only, the value of the constant, K, is 3/16.

4. The above relationship is not influenced by variation of the weight and geometry of the propeller and gear assemblies, or by variation of the span between the stern tube bearings.

5. The number of bearings in the system has a major effect on the gear manufacturer's alignment criteria. To permit maximum stern tube weardown, an even number of bearings system should be aligned so that R_2 is greater than R_1 by the allowable load differential, while for an odd number of bearings system, an analysis must be made to determine the more important effect, either stern tube weardown or gear case expansion.

6. The results of this investigation may be used in the preliminary design of single screw, low RPM shaft systems.

VI.

RECOMMENDATIONS

It is recommended that the program of investigation started by this group be continued. The results obtained thus far indicate the existence of a direct relationship between shaft stress, alignment, and line shaft arrangement, but are limited in scope. The following specific recommendations are made:

1. Future investigations should be conducted to further determine the effects of variation of the physical shaft dimensions and loads.
2. The range of the investigation should be expanded to include all types of shaft systems, particularly those operating at higher RPM.
3. The effect of vertical alignment upon the buckling stability of the shaft should be investigated to determine possible limits for vertical alignment.
4. The present shaft system computer program should be modified so that the RIN output will be accurate to two decimal places.

5. A computer program should be devised which will determine the optimum bearing spacing for various alignment criteria. Such a program should include limitations for maximum bearing loads, critical natural frequency and buckling stability. It should compute the shaft diameter for each condition of alignment. The suggested alignment criteria are:

   (a) $R_1 = R_2$; bearing pressures at all water lubricated bearings equal, pressures of all oil lubricated bearings equal.

   (b) $R_1 = R_2$; The maximum shaft bending moments at all bearing location equal.

This program could be used to develop design charts for the use of those who do not have access to a computer. It could also be used to design, arrange and determine the required alignment of any shaft system.

6. Following the development of design charts, the effect of stern tube weardown should be investigated to determine new allowable limits which will not adversely affect the system alignment.

VII. APPENDIX

APPENDIX "A"

SUPPLEMENTARY INTRODUCTION

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SUPPLEMENTARY INTRODUCTION

1. Problems of the Shaft System

The increased use of higher shaft powers, shorter shafts and an increased interest in noise reduction has brought to light many new problems in the shafting system and increased the importance of many others, previously considered as inconsequential. These problems can best be discussed by segregating the system into three areas of major interest:

(1) Tailshaft and stern tube area.

(2) Lineshaft area.

(3) Reduction gear area.

Tailshaft Area

The major problem encountered in the tailshaft area is caused by the large weight of the overhanging propeller. This tends to unload the next to last (forward stern tube) bearing, and overload the after part of the last (after stern tube) bearing. As the last bearing wears, which is similar to a support settlement, the loads on the rest of the bearings change. This is considered as a misalignment

in the sense that the load distribution has changed from the original set-up.

In addition, the center of pressure of the long after stern tube bearing will shift forward with weardown. Although the exact amount of this shift is not definitely determined, unpublished work by Boston Naval Shipyard and General Electric, Lynn Gear Works, indicate that the initial center of support of a new stern tube bearing is approximately located one shaft diameter from the after end of the bearing. After weardown, the support is best represented by four or five equal supports distributed over the length of the bearing, with the settlement at these individual locations equal to the location weardown.

In considering the possible unloading of the next to last bearing, some of the effects which may result are:

(1) An unintentional increase of span. This may lower the natural frequency of lateral vibration into the operating range.

(2) An increased, non-critical, lateral motion of the shaft. This motion, generally a maximum in the region of the packing gland, causes rapid destruction of the packing.

Non-concentricity of thrust also has an effect in this area. The superimposed moment of thrust can increase or decrease the shaft bending moments and bearing loads, depending upon the actual location of the center of thrust. At present the magnitude of this moment is not sufficiently defined to be considered in the alignment problem. However, due to the possible severity of this moment, it should be considered in strength calculations.

Line Shaft Area

The major deficiency in the line shaft area is concerned with the longitudinal location of the line shaft bearings. Some of the criteria in use for locating these bearings are arbitrary and apparently have no real justification. Examples of this are:

1. Two bearings are provided for each shaft span, so located that the slope and deflection of the uncoupled shaft at the flange is zero.

2. Equal lengths of line shaft are provided, each with a specified number of bearings, symmetrically located from section to section.

3. Bearings are spaced at a specified number of shaft diameters (11).

4. Certain bearings are located by tradition, an example of which is the practice of using two water lubricated stern tube bearings.

The major objection to such criteria is that they are not based on a consideration of the shaft system as a whole. The major effect of such criteria is that an excessive number of bearings are required, resulting in a system that is very stiff, lightly loaded, and consequently extremely sensitive to misalignment.

Reduction Gear Area

Problems in the reduction gear area result from the fact that any significant mismatch of the gear faces will cause serious injury to the tooth surfaces, or complete tooth failure. The manufacturer usually specifies the required alignment of the gear faces in terms of maximum load differential for the bull gear bearings. This load differential must be satisfied with the reduction gear hot and expanded vertically. In addition, the load must be within reasonable limits when the gear is cold.

The exact amount that the gear case will expand cannot be determined analytically. Experimental determination is

necessary and the amount will vary with different gear cases and different manufacturers. Evidence indicates, this expansion generally varies from 10 to 40 mls with an average of about 20 mils. The allowable mismatch, and hence load differential for the bull gear bearings also varies with different gears and gear manufacturers. It is felt that an average load differential of the order of magnitude of 5000 pounds is not difficult to attain. These average values have been used in actual alignment calculations and have produced satisfactory results.*

* Discussion with H.C. Anderson of the General Electric Co. and E. Antkowiak of the Boston Naval Shipyard.

APPENDIX "B"

SUPPLEMENT TO THE THEORY

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SUPPLEMENT TO THE THEORY

1. Effect of Increased Shaft Span

The many problems of the shaft system have been considered in terms of three separate areas. Therefore, the effect of increasing the shaft span can most easily be realized through a similar discussion.

Tailshaft Area

Increased bearing span will decrease the possibility of unloading the forward stern tube bearing. Not only does the increased flexibility reduce the influence of the overhanging propeller weight, but the increased span of the distributed shaft weight contributes significantly to loading the forward stern tube bearing.

The effect of stern tube bearing weardown will be reduced because of the increased shaft flexibility (lower RIN) associated with these bearings. Also, the adverse effects of unpredicted eccentric thrust will be reduced due to the increased flexibility and more uniform initial bearing loading.

Lineshaft Area

The major effect of increased span in this area is to reduce the transmitted effects of the propeller overhang and of stern tube weardown. The increased flexibility also provides for an inherently more uniform heavy loading and reduced deviation from design loads through unintentional misalignment of individual bearings, caused by unknown factors previously mentioned.

Reduction Gear Area

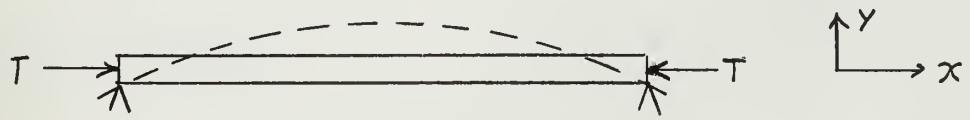
One of the greatest benefits of increased bearing span is the simplification of the reduction gear alignment problem. It must be realized, that the gear itself is fixed in its dimensions and that the gain here is accomplished through increased lineshaft span. The gear manufacturer is forced to provide a short span between gear bearings to avoid excessive bending deflections along the gear face. In addition, in the straight line condition, the after gear bearing will have a greater load than the forward bearing due to the weight distribution of the lineshaft. Past practice has been to place the first lineshaft bearing close enough to the after gear bearing to obtain a satisfactory gear bearing load split, but this makes the gear very sensitive to the slightest misalignment from any source.

By increasing the span between the after gear bearing and the first line shaft bearing, the RIN of the gear and lineshaft bearings are lowered. At the same time the gear bearing load distribution becomes more severe, but this may be corrected by intentional misalignment of the lineshaft bearings. The end result is a gear system which is insensitive to unintentional misalignment from any source and which may have more accurately controlled bearing loads.

2. Natural Frequency of Lateral Vibration for Lineshaft Spans

This derivation is similar to that for a simply supported, uniformly loaded beam such as may be found in most vibration textbooks. However, in this case provision is made for axial loading of the span.

Consider the simply supported beam of length L shown below:



The bending moment at x is given by the equation

$$M = \iint E\,I\,\frac{d^4y}{dx^4}\,dxdx - Ty \qquad (10)$$

from which the "loading" per running inch, P,

$$P = E\ I\ \frac{d^4y}{dx^4} - T\ \frac{d^2y}{dx^2} \tag{11}$$

If the beam is in a state of sustained vibration the "loading" acting is an alternating inertia load, or

$$m\ \frac{d^2y}{dt^2} = E\ I\ \frac{d^4y}{dx^2} - T\ \frac{d^2y}{dx^2} \tag{12}$$

where

$$m = \frac{W}{g}$$

Assuming simple harmonic motion and the solution

$$y = C \sin \frac{\pi x}{L} \tag{13}$$

there results

$$m\omega^2 - \frac{E\ I\ \pi^4}{L_n^4} + \frac{T\ \pi^2}{L_n^2} = 0 \tag{14}$$

from which we obtain

$$f(cpm) = \frac{30}{\pi} \sqrt{\frac{E\ I\ \pi^4}{m\ L_n^4} - \frac{T\ \pi^2}{mL_n^2}} \tag{15}$$

3. Types of Shaft Systems

In the attempt to establish a representative system

for analysis, it was necessary to distinguish between solid and hollow shafts and between single and multi-screw systems. The solid shaft was chosen as being most representative for the merchant type ship used in the analysis.

A simple qualitative comparison of the use of single and multi-screw shaft systems suffices to indicate that single screw shaft systems generally operate at a lower RPM than the multi-screw systems. This in turn indicates that, for equal powering requirements, the single screw system will have heavier concentrated gear and propeller loads. It must also be realized that the single screw system propeller will be heavier as it operates in a region of more severe wake variation which necessitates increased strength requirements.

From the foregoing, it is anticipated that the single screw solid shaft system will create the most severe conditions of loading. On this basis, it may be assumed that any qualitative results of such a system analysis will be equally valid for a multi-screw hollow shaft system.

APPENDIX "C"

SUPPLEMENT TO THE PROCEDURE

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SUPPLEMENT TO THE PROCEDURE

1. Development of the Family of Shaft Systems

Propeller Weight

In attempting to determine the propeller weight, unless BTF, MWR, and the number of blades are known, none of the usual formulae can be utilized. Fortunately, a set of curves was made available which portrayed the required information; W_p vs SHP and RPM (Fig. V)*. This set of curves was developed by Tassaron and is used by LIPS Screw Works, Ltd., Drunen, Holland for preliminary propeller weight estimates. A comparison of the statistical data with these curves shows that, with few exceptions, the actual propeller weight varies from the predicted weight by less than 12 per cent.

Propeller Inertia

In order to determine the propeller inertia, the various blade sections should be known. Since these were not avail-

* From the files of Prof. L. Troost, Department of Naval Architecture, M.I.T. (origin unknown).

able, the approximation

$$I_x = \frac{W_p r^2}{2 g} \tag{16}$$

was used (11), where

$$r = 0.20 \text{ to } 0.22 D_p \tag{17}$$

Taking a mean $r = 0.21 D_p$, it is still necessary to determine the propeller diameter. If it is assumed that the propeller is designed for the largest practical diameter and highest propulsive efficiency at optimum RPM, with a given SHP and RPM we can solve for the maximum diameter by using the relationships developed by Troost (12). By using a weighted mean coefficient for the relationships, SHP = 1.06 PHP and inverting (12) there results

$$D_p = \frac{48.16 \text{ SHP}^{0.2}}{N^{0.6}} \tag{18}$$

With D_p we can solve for $W_p r^2$ by using W_p from Tassaron's curves (Fig. V). This results in a series of curves of $W_p r^2$ as a function of SHP and RPM (Fig. VI). A comparison of the few available values of $W_p r^2$, in this operating range, shows little difference between calculated and statistical values.

Length of Shaft from Stern Tube to Propeller

An analysis of the statistical data indicated that this length is independent of SHP and RPM, and is a function of shaft diameter. Fig. II portrays the data and the fitted curve. It is seen that

$$L_p \approx 2.1\, D_{ts}$$

Shaft Diameter

The shaft diameter was calculzted on the basis of the combined stress relationship used by the Bureau of Ships, U.S. Navy (7). This combined stress formula is given by

$$\frac{\sigma_{sr}}{\sigma_{yp}} + \frac{\sigma_{ar}}{\sigma_{fl}} = \frac{1}{F.S.} \qquad (19)$$

Lineshaft F.S.	1.75
Tailshaft F.S.	2.00

The stress equation should ordinarily be investigated for both full power RPM and for that RPM at which the torsional critical occurs. It is very seldom, however, that the resonant stress is greater than the full load stress; hence we assume that the critical stress condition occurs at full power.

a. Steady shear stress

$$\sigma_s = \frac{5.1 \times 63{,}025 \text{ SHP}}{D^3 \times \text{RPM}} \qquad (20)$$

b. Steady compressive stress

$$\sigma_c = \frac{415\ Q}{D^2\ 63{,}025} \left[\frac{PC \times RPM}{V_k\ (1-t)} \right] \qquad (21)$$

From a study of statistical data, it may be seen that the following approximate relationships hold

$$\left(\frac{PC}{1-t}\right)_{\text{merchant}} > \left(\frac{PC}{1-t}\right)_{\text{naval}}$$

$$\left(\frac{RPM}{V_k}\right)_{\text{merchant}} < \left(\frac{RPM}{V_k}\right)_{\text{naval}}$$

Consequently, it is expected that, for both merchant and naval ships

$$\frac{PC \times RPM}{V_k\ (1-t)} = \text{"F"} \simeq \text{constant}$$

From Ref. 12, the following data is typical of merchant ships:

C_B	PC/1-t	RPM/V_k	"F" = $\frac{PC \times RPM}{(1-t) \times V_k}$
.60	.899	4.796	4.312
.65	.902	4.146	3.739
.70	.917	4.303	3.946
.75	.948	4.242	4.021
.80	.975	4.372	4.263
			Ave = 4.056

From Ref. 7, for a typical destroyer:

$$P.C. = .625$$

$$t = .035$$

$$V_K = 33.1$$

$$RPM = 320$$

$$\text{"F"} = \frac{PC}{(1-t)} \times \frac{RPM}{V_K} = 6.255$$

For this destroyer, $Q = 6{,}900{,}000$ in-lb.

$$T = .0323Q = 223{,}000 \text{ lb.}$$

$$\sigma_s = 8610 \text{ psi and } \sigma_c = 1385 \text{ psi}$$

and neglecting σ_c, $\sigma_{sr} = 17{,}220$ psi

while including σ_c, $\sigma_{sr} = 17{,}280$ psi

Since "F", for the merchant ship is not very much different from "F" destroyer, similar results would prevail for the merchant ship. Taking a conservative attitude, we assume for the calculations, that the resultant steady stress is increased 3% by the effect of σ_c.

With this assumption, $\sigma_{sr} = 2.03\ \sigma_s$ (22)

c. Alternating bending stress

$$K_b\ \sigma_b = \frac{K_b \times 10.2\ M_b}{D^3} \qquad (23)$$

In the tailshaft $K_b = 1.0$ is assumed as there is usually no configuration to cause bending stress concentration at the point of maximum M_b. M_b is the combined moment due to propeller overhang (M_g) and eccentric thrust (M_{oc}). The thrust eccentricity is not known nor is there any method currently available for predicting the eccentricity with accuracy greater than 50% due to inaccuracy of the wake calculations (4). Therefore, it is necessary to make an assumption as to the nature of thrust eccentricity.

The Bureau of Ships (7) specifies that the moment due to eccentric thrust (M_{oc}) should equal $2\ W_p L_p$ for single screws and $W_p L_p$ for multi-screw ships and that $\sigma_b \leqq 6000$ psi. Investigation of these values reveals that although apparently arbitrary, some justification for their use exists (8).

Further investigation indicates that the worst configuration for eccentric thrust is encountered with a four-bladed propeller (Fig. XVI), for which we may say:

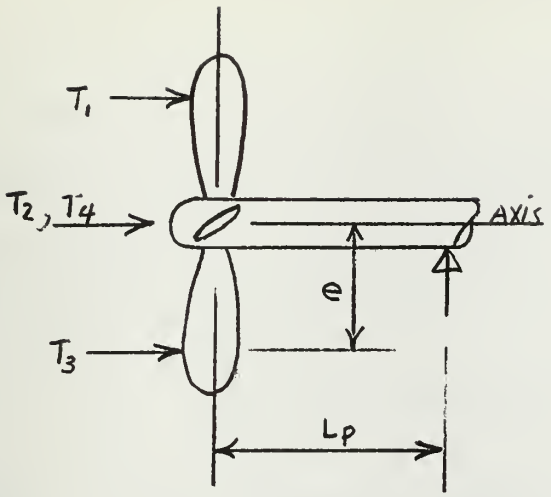
$$T_t = T_1 + T_2 + T_3 + T_4$$

For the single screw ship under consideration:

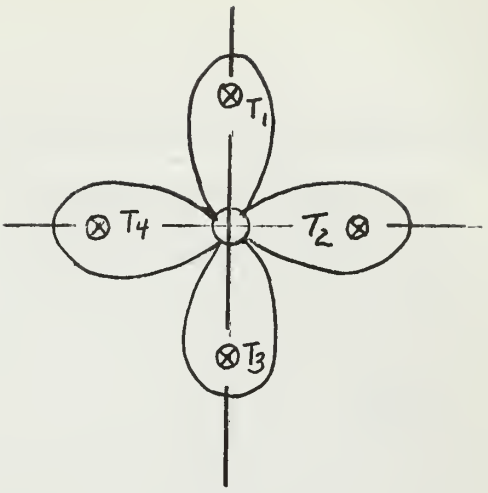
$$T_t \times e_t = M_{oc} = 2\ W_p L_p$$

It is then assumed that the longitudinal and transverse components of wake are symmetrical about the center line of

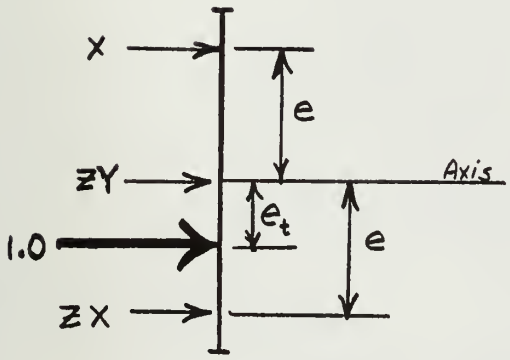
FIGURE XVI



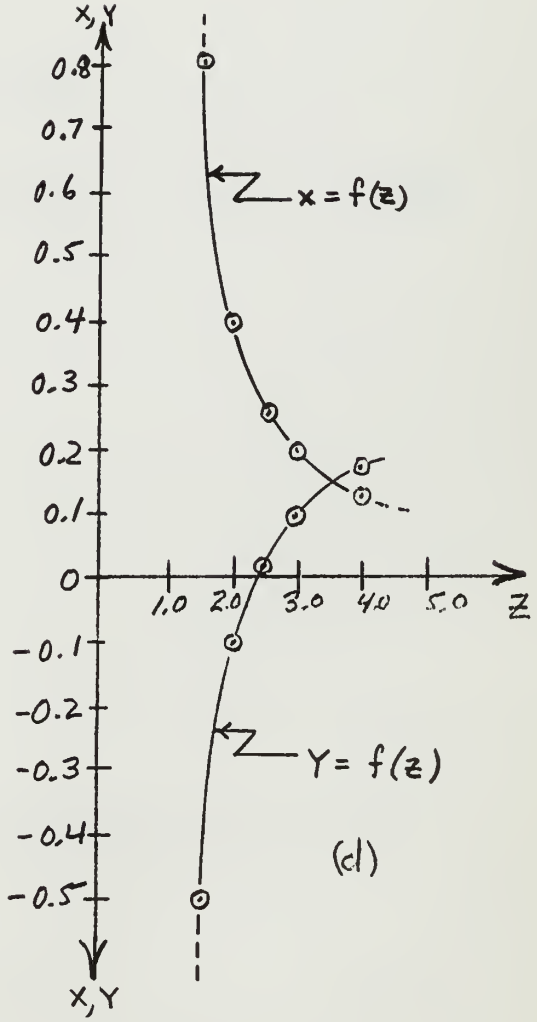
(a)



(b)



(C)



(d)

ECCENTRIC THRUST ANALYSIS

FOUR BLADE PROP

the ship. In this case it is also assumed that the tangential variation is small or negligible for symmetrical positions. With these conditions imposed, the torque bending moment in the vertical plane is zero, or

$$\sum_{2,4} \int L_p \; dQ/R' = 0 \qquad (24)$$

where R' = propeller radius

and $T_2 = T_4$

It may also be observed (4), that

$$e = x/R' \approx 0.65 \; x \; e_1 \approx e_2 \approx e_3 \approx e_4 \qquad (25)$$

We than say:

$$T_1 = x \; T_t$$

$$T_3 = Z \; x \; T_t$$

$$T_2 = T_4 = y \; T_t$$

from which we obtain:

$$1 = x(1-Z) + 2y \qquad (26)$$

Taking moments about a diameter in the horizontal plane there results:

$$2 \; e \; (y+Z \; x) = e_t + e \qquad (27)$$

Combining (26) and (27)

$$\frac{e_t}{e} = x(Z-1) \qquad (28)$$

It is then necessary to evaluate e_t as defined in equation (28). This evaluation is shown below:

Ship	SHP	RPM	T	M_g	e_t
USNS James E. Robinson (8)	8,500	85	132,000	177,500	0.263
SS Cryssi (10)	15,000	112	177,000	219,000	0.256
Hypothetical	20,000	100	264,000	386,000	0.264

It is assumed that $e_t = 0.26$. From (25) and (28) there is obtained:

$$0.4 = x(Z-1) \qquad (29)$$

Using (26) and (29), Fig. XVI(d) is obtained from which is seen that the use of $2 W_p L_p$ for M_{oc} is justified if the thrust distribution factor, Z, is greater than 2.5. This indicates that the existence of a very severe condition of thrust distribution is necessary to obtain the prescribed M_{oc}. However, it is possible that such a distribution may occur with the ship in a light condition or pitching in a seaway. Any condition of greater severity is hard to visualize. It is therefore assumed that

$$(K_b \sigma_b)_{tailshaft} = \frac{30.6 W_p L_p}{D^3} \qquad (30)$$

In the lineshaft $K_b \approx 1.9$ (average value, reference 7, Fig. 3); M_b is the maximum bending moment in the lineshaft span and is approximately equal to the moment for a clamped end beam. Since it is assumed that the maximum moment in the lineshaft equals that in the tailshaft, then $M_b = W_p L_p$ and

$$(K_b \sigma_b)_{\text{lineshaft}} = \frac{40.7\ W_p\ D_{ts}}{D_{ls}^3} \tag{31}$$

d. Alternating shear stress

$$(K_t\ \sigma_{sa}) = \frac{K_t\ G\ D\ \phi}{2L} \tag{32}$$

Unfortunately ϕ is indeterminate in this analysis, however

$$\phi = 0.025\ \frac{\text{Alt. propeller torque}}{\text{mean propeller torque}} \times \frac{1}{B}$$

For destroyers (7)

$$\sigma_{sa} \approx 5\%\ \sigma_s$$

and for merchant ships*

$$\sigma_{sa} \approx 10\text{-}12\%\ \sigma_s$$

---

* Course notebook, "Mechanical Vibrations" by Professor F.M. Lewis.

We assume

$$\sigma_{sa} = 10\% \ \sigma_s \tag{33}$$

and

$$K_t = 1.9 \tag{34}$$

Then for both tailshaft and lineshaft

$$(K_t \ \sigma_{sa}) = \frac{61{,}071 \ SHP}{D^3 \ RPM} \tag{35}$$

Finally it is assumed that the shafting material is Class 2 steel, and that

$$\sigma_{yp} = 30{,}000 \text{ psi}$$

$$\sigma_{fl} = 27{,}000 \text{ psi}$$

Combining the individual stress components in the combined stress relationship, equation (1), there results

Tailshaft:

$$\frac{1}{2.0} = \frac{652{,}500 \ SHP}{D_{ts}^3 . N. \ \sigma_{yp}} + \frac{\sqrt{\left(\frac{64.26 \ W_p}{D_{ts}^2}\right)^2 + \left(\frac{122{,}142 \ SHP}{D_{ts}^3 \ N}\right)^2}}{\sigma_{fl}} \tag{36}$$

Lineshaft:

$$\frac{1}{1.75} = \frac{652{,}500 \ SHP}{D_{ls}^3 . N. \ \sigma_{yp}} + \frac{\sqrt{\left(\frac{40.7 \ W_p D_{ts}}{D_{ls}^3}\right)^2 + \left(\frac{122{,}142 \ SHP}{D_{ls}^3 \ N}\right)^2}}{\sigma_{fl}} \tag{37}$$

The curves resulting from these equations are shown as D_{ls} and D_{ts} as a function of SHP and RPM (Fig. VII). Comparison of these results with statistical data indicates that, in the majority of cases, the curves are slightly conservative; i.e., a larger diameter shaft is prescribed by the curves than is installed in the ship.

Gear Weight

A review of the statistical data did not present any clear-cut trend for the gear weight as a function of the independent variables SHP and RPM. It was decided to consider

$$W_g = f(L_f, D_{g2})$$

where D_{g2} is the bull gear diameter. Then combining the relationship for tooth pressure and the Hertz equation for compressive stress between two cylinders (11) it is determined that

$$D_{p2} = C_1 \sqrt[3]{K\left(\frac{1}{L_f / D_{p2}}\right)\left(\frac{SHP}{RPM}\right)\left(\frac{r_2 + 1}{r_2^2}\right)}$$

where

K = design factor for gears
D_{p2} = low speed pinion diameter
r_2 = second reduction ratio

Also

$$D_{g2} = D_{p2}\, r_2$$

$$L_f = C_2\, D_{p2}$$

From the geometry of the gear it was suspected that

$$W_g \propto L_f\, D_{g2}^{n}$$

or, neglecting the variation in K, C_2, and r_2*

$$W_g \propto \left(\frac{SHP}{RPM}\right)^{\frac{n+1}{3}}$$

Trial plots of the data, with various values of n, indicated that n = 1 provided the most satisfactory distribution of the statistical data. A root mean square solution for the data was performed with the results shown in Fig. IV.

Because of the large variation in W_g, a trial system was computed (G-2 series, Appendix "F") using a shaft system picked at random from the statistical data. The value of W_g was varied plus 15% and minus 30% from that

---

* From the statistical data it is seen that r_2 varies from 6.5 to 8.7, C_2 from 1.9 to 2.2 and K from 60 to 80. Although these variations are not large, their combined effect on either D_{g2} or L_f may be quite large. However the variation of D_{g2} and L_f counter each other.

indicated by Fig. IV. The resultant change in reactions and moments for the gear bearings and the first lineshaft bearing are shown in Table X below.

TABLE X

Per Cent Change in Bearing Reactions and Shaft Moments for Per Cent Change in W_g

System	W_g	ΔW_g	ΔR_1	ΔR_2	ΔR_3	ΔM_2	ΔM_3
G-2	43,609	-	-	-	-	-	-
G-2-A	50,200	+15	+10.9	+5.5	-0.14	+1.1	-0.3
G-2-B	30,500	-30	-21.7	-11.1	+0.28	-2.2	+0.6

These results indicate that, outside of the gear span, the system is relatively insensitive to changes in W_g. Fig. IV was therefore considered acceptable for use in the development of the shaft system families, subject to further investigation in the family analysis.

Gear Face Length (L_f)

By reasoning similar to that used in reducing the gear weight, the possible relationship

$$L_f \propto \left(\frac{SHP}{RPM}\right)^{1/3}$$

was determined. A plot of the statistical data using this relationship gave reasonable results. The resultant root mean square curve is shown in Fig. III. Random trials with other relationships produced completely negative results.

Gear Hub Diameter (D_h)

There is no definite design criteria here which could be used to indicate a suitable relationship. However, the desire to keep the deflection of the gear low would result in keeping D_h proportional to W_g or

$$D_h \propto \left(\frac{SHP}{RPM}\right)^{2/3}$$

Although the plot and fitted curve, Fig. VIII, were not particularly good, no more favorable relationship could be found. The curve was therefore considered representative, subject to later investigation of the effect of gear stiffness upon the system characteristics.

Length Between Gear Bearing (L_b)

Consideration of the gear stiffness (I/L_b) indicated a relationship similar to that for D_h, however this did not produce reasonable results. It was finally determined by trial and error that

$$(L_b - L_f) \propto \left(\frac{SHP}{RPM}\right)^{2/3}$$

produced the most favorable data spread. The fitted curve using this relationship is shown in Fig. VIII. As for D_h, the investigation of the effect of varying L_b was delayed until final analysis.

Diameter of the Gear Shaft (D_{gs})

In considering the gear shaft it was suspected that the diameter would be governed by deflection considerations; however, trial plots of the data did not prove satisfactory. Following the possibility that the gear shaft diameter was governed more strictly by combined stress, the data was plotted proportional to the lineshaft diameter. The results were considered satisfactory and the curve fitted as shown in Fig. IX.

Equivalent Gear Weight (ΔW_g)

The weight of the equivalent gear is determined by calculating the weight of the gear hub and shaft assembly and subtracting from the total gear weight (W_g). The equivalent gear weight is then applied as a concentrated load at the center of the gear. This equivalent weight was calculated only for the nine families considered.

APPENDIX "D"

STATISTICAL DATA

APPENDIX "D"

Statistical Data for Merchant Ship Shaft Systems

System	SHP	RPM	D_{ts}	D_{ls}	L_p	W_p	W_g
1	10,000	120	19.56	17.00	47.5	28,000	40,500
2	18,750	106	24.42	22.00	57.42	75,600	74,150
3	4,000	165	13.50	11.38	25.25	9,240	13,600
4	18,500	102	24.42	22.00	49.61	73,000	54,400
5	11,000	93	22.28	19.13	44.97	49,500	41,275
6	16,000	102	22.42	21.00	46.61	71,500	69,257
7	9,000	90	20.00	18.00	45.50	42,600	46,998
8	17,500	102	23.30	21.65	46.46	80,000	73,431
9	12,500	107	22.00	19.00	45.50	43,400	52,587
10	20,000	107	26.25	22.25	62.25	66,370	67,090
11	25,000	100	27.87	24.50	55.87	83,000	95,000
12	3,000	92	16.61	12.44	32.91	19,400	17,165
13	19,000	103	24.00	21.63	55.05	67,000	66,200
14	15,780	102	24.00	21.25	43.77	57,000	40,662
15	9,000	100	21.00	17.50	53.75	45,600	27,000
16	12,500	100	22.12	19.68	45.41	50,400	49,583
17	18,600	101	-	-	-	72,100	-
18	8,500	85	-	-	-	40,980	-
19	4,000	90	-	-	-	27,600	-
20	8,500	85	-	-	-	-	64,567
21	5,000	90	-	-	-	-	45,200
22	9,000	107	-	-	-	-	43,240

System	L_b	L_f	D_h	L	ΔR_{gear}	R_2	R_{oa}
1	56.3	37.75	36.00	2530.5	5,000	7.69	53.69
2	70.5	56.63	42.25	1100.4	5,000	7.28	61.45
3	41.0	27.50	27.00	1254.7	5,000	7.05	35.10
4	71.0	45.00	37.50	730.9	10,000	6.87	61.60
5	61.0	35.50	40.00	2384.3	7,500	7.26	67.70
6	70.5	43.00	42.25	698.1	10,000	7.28	64.00
7	61.0	35.50	40.00	1641.0	7,000	7.62	71.00
8	70.5	43.00	42.25	2510.1	5,000	7.28	64.09
9	68.0	42.50	40.00	2320.1	6,000	6.86	61.50
10	71.5	48.00	40.00	2491.0	7,000	7.24	60.79
11	85.0	54.87	46.00	1110.2	14,000	6.74	60.90
12	41.0	24.75	27.00	556.1	2,500	9.67	97.06
13	80.5	47.00	42.00	1147.3	14,000	7.38	57.00
14	71.2	42.50	45.00	949.5	9,000	6.80	60.90
15	53.5	35.00	32.00	818.4	5,000	8.75	96.06
16	68.0	49.00	40.00	792.1	5,000	-	-
17	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-
20	65.0	45.0	39.5	-	-	8.89	72.5
21	57.0	37.5	23.5	-	-	9.59	66.0
22	59.8	41.3	36.75	-	-	6.95	57.2

System	RPM (turbine)	K	L_f/D_{p2}	L_n/D_{1s}	D_{gs}	$Wr^2 \times 10^{-6}$
1	6443	66.2	1.78	12.7	18.40	-
2	6514	76.3	2.03	9.3	26.00	-
3	5791	-	-	16.2	13.00	-
4	6514	-	-	7.3	25.50	-
5	6302	72.1	2.17	14.5	25.00	-
6	6538	79.6	1.94	7.8	26.00	-
7	6398	-	-	14.0	25.50	-
8	6533	78.2	2.13	15.4	26.00	-
9	6593	79.4	2.07	12.0	25.50	-
10	6504	-	-	12.9	31.50	-
11	6090	71.5	1.98	7.2	30.12	-
12	8901	95	2.07	-	17.60	-
13	5870	72.1	2.14	-	20.00	-
14	6210	63.0	2.07	-	20.00	-
15	9606	84.3	1.97	12.4	13.50	-
16	-	72.3	2.09	-	-	-
17	-	-	-	-	-	216.0
18	-	-	-	-	-	123.3
19	-	-	-	-	-	56.3
20	6160	58.8	-	-	16	-
21	5940	58.2	-	-	15	-
22	6130	59.4	-	-	12.5	-

APPENDIX "E"

SAMPLE CALCULATIONS

APPENDIX "E"

Sample Calculations

1. Frequency Calculation

   a. Lineshaft-S-5-L_n (max)

Basic Eqn. (15): $f = \frac{30}{\pi}\sqrt{\frac{E\,I\,\pi^4}{m\,L^4} - \frac{T\,\pi^2}{m\,L^2}}$ where $m = \frac{W_{ls}}{g}$

SHP = 12,500 ; RPM = 105

From Table I, obtain D_{ls}, calculate W_{ls} and I

D_{ls} = 19.67; W_{ls} = 86 lb/in; I = 7,320 in^4

From Eqn. 21, $T = 326\,\frac{SHP}{RPM}\,4.056$ = 157,000 lb

Then f = 279 cpm on rigid bearing

f = 112 cpm reduced 60% for bearing elasticity

   b. Tailshaft-S-5-50% L_1 (max)

Basic Eqn. (Ref. 9)

$$f = \frac{30}{\pi}\sqrt{\frac{I\,E}{I_x(L_p + \frac{L_1}{3}) + \frac{W_p L_p^2}{g}(\frac{L_p}{2} + \frac{L_1}{3}) + m(\frac{L_p^4}{8} + \frac{L_1 L_p^3}{9} + \frac{7L_1^4}{360})}}$$

SHP = 12,500; RPM = 105

From Table I, $50\%\ L_l(\max) = 257$ in

$L_p = 46.20$ in

$Wr^2 = 124.5 \times 10^6$ lb-in^2

$W_p = 64{,}000$ lb (increased 25% for entrained water)

$$I_x = 1/2\ \frac{Wr^2}{g} \times 1.6 = 2.58 \times 10^5 \text{ in-lb-sec}^2$$

(increased 60% for virtual inertia of entrained water)

Then, $f = 570$ cpm

2. Sample Series Analysis (S-5-all)

a. Required Data:

D_{gs}	22.8	$70\%\ L_n(\max)$	402.5
D_{ls}	19.67	$80\%\ L_n(\max)$	460.0
D_{qs}	22.01	$90\%\ L_n(\max)$	517.5
L_b	63.3	$M_b(\max)$	2365
L_l	250		

b. Consider computer solution S-5-701 and analyze

No. 4	No. 3	No. 2	No. 1	
66,378	22,099	66,548	4,088	R_o (lb)
-46.3	99.3	-207.2	+154.2	RIN No. 3 on (lb/mil)
-8002	+17162	-35810	+26650	ΔR No. 3 up 172.83 mil
58376	39261	30738	30738	R aligned (lb)
0	+8002	-9160	+26650	Δ Shear (lb)
	+2000.50	-3686.90	+1686.94	$\int$ Δ Shear (Kip-in)
+0.54*	-1999.96	+1686.94	0	ΔM (Kip-in)
-2151.44	-674.65	-1408.67	-7.5	M_o (Kip-in)
-2151.98	-2674.25+	+278.27	-7.5	M (Kip-in)
-	1.5	1.0	1.0	L/D oil bearings
-	54.6	59.4	59.4	Bearing pressure (psi)

* Closure error

\+ Maximum moment

c. Perform similar calculation for the remaining eight systems in the series.

d. Plot results of calculations, Fig. XI, to determine intercept with M_b. The intercept is the limiting % L_n(max).

APPENDIX "F"

CALCULATED DATA

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH [redacted] lbs	SLOPE RADIANS	DEFLECT. INCHES	
000.00	132.8	052369	000000	0000000		-.00001	.0002	
0018.00	132.8	052369	029297	-0002390	-0021514	-.00001	.0000	BRG
0036.00	392.8	458236	000000	0024516	0441282	-.00000	-.0001	
0064.00	392.8	458236	-043609	0013516	0973726	.00000	-.0001	
0092.00	132.8	052369	000000	-0041093	-0022870	.00001	-.0000	
0110.00	132.8	052369	061514	-0043483	-0784049	-.00001	.0000	BRG
0178.75	132.8	052369	000000	0008901	0141738	-.00004	-.0025	
0247.50	132.8	052369	000000	-0000229	0439819	.00000	-.0042	
0316.25	132.8	052369	000000	-0009360	0110193	.00004	-.0023	
0385.00	132.8	052369	036744	-0018490	-0847140	.00000	-.0000	BRG
0453.75	132.8	052369	000000	0009123	0093944	-.00004	-.0020	
0522.50	132.8	052369	000000	-0000007	0407320	.00000	-.0036	
0591.25	132.8	052369	000000	-0009137	0092990	.00004	-.0020	
0660.00	132.8	052369	036785	-0018267	-0849047	-.00000	-.0000	BRG
0728.75	132.8	052369	000000	0009387	0110193	-.00004	-.0024	
0797.50	132.8	052369	000000	0000257	0441725	-.00000	-.0042	
0866.25	132.8	052369	000000	-0008873	0145551	.00004	-.0025	
0935.00	132.8	052369	035242	-0018003	-0778330	.00001	-.0000	BRG
1003.75	132.8	052369	000000	0008109	0092990	-.00003	-.0013	
1072.50	132.8	052369	000000	-0001022	0336603	.00001	-.0023	
1141.25	132.8	052369	000000	-0010152	-0047491	.00003	-.0007	
1210.00	132.8	052369	041372	-0019282	-1059291	-.00003	-.0000	BRG
1278.75	132.8	052369	000000	0012960	0145550	-.00009	-.0051	
1347.50	132.8	052369	000000	0003830	0722684	-.00002	-.0093	
1416.25	132.8	052369	000000	-0005301	0672112	.00008	-.0074	
1485.00	132.8	052369	018395	-0014431	-0006168	.00013	-.0000	BRG
1553.75	132.8	052369	000000	-0005166	-0047491	.00013	.0088	
1622.50	132.8	052369	000000	-0014296	-0716520	.00009	.0167	
1691.25	132.8	052369	000000	-0023427	-2013257	-.00009	.0177	
1760.00	115.5	052369	104953	-0032557	-3937700	-.00047	-.0000	BRG
1817.00	115.5	052369	-065812	0065815	0001329	-.00068	-.0348	
1817.01	000.0	000000	000000	2	0001329	-.00068	-.0348	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00644	-00917	00346	-00093	00025	-00007	00002	-00000	00000	0000
N02	-00917	01346	-00585	00197	-00053	00014	-00004	00001	00000	0000
N03	00346	-00585	00435	-00289	00118	-00031	00008	-00001	00000	0000
N04	-00093	00197	-00289	00367	-00271	00113	-00028	00005	00000	0000
N05	00025	-00053	00118	-00271	00361	-00268	00105	-00017	00000	0000
N06	-00007	00014	-00031	00113	-00268	00353	-00239	00065	00000	0000
N07	00002	-00004	00008	-00028	00105	-00239	00249	-00092	00000	0000
N08	-00000	00001	-00001	00005	-00017	00065	-00092	00040	00000	0000

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
29296	61514	36743	36785	35242	41372	18395	104953	00000	00000

G-2-A

PROB NO G-2-A FEB. 1960

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS	SLOPE RADIANS	DEFLECT. INCHES	
000.00	132.8	052369	000000	0000000		-.00001	.0002	
0018.00	132.8	052369	032494	-0002390	-0021514	-.00001	.0000	BRG
0036.00	392.8	458236	000000	0027713	0498827	-.00000	-.0002	
0064.00	392.8	458236	-050200	0016713	1120787	.00000	-.0002	
0092.00	132.8	052369	000000	-0044487	0029157	.00001	-.0000	
0110.00	132.8	052369	064950	-0046877	-0793115	-.00001	-.0000	BRG
0178.75	132.8	052369	000000	0008943	0135547	-.00004	-.0024	
0247.50	132.8	052369	000000	-0000188	0436502	.00000	-.0041	
0316.25	132.8	052369	000000	-0009318	0109750	.00004	-.0023	
0385.00	132.8	052369	036691	-0018448	-0844708	.00000	.0000	BRG
0522.50	132.8	052369	000000	-0000018	0408207	.00000	-.0036	
0660.00	132.8	052369	036800	-0018279	-0849706	-.00000	.0000	BRG
0797.50	132.8	052369	000000	0000260	0441501	-.00000	-.0042	
0935.00	132.8	052369	035238	-0018000	-0778119	.00001	.0000	BRG
1072.50	132.8	052369	000000	-0001023	0336620	.00001	-.0023	
1210.00	132.8	052369	041376	-0019284	-1059468	-.00003	.0000	BRG
1347.50	132.8	052369	000000	0003832	0722850	-.00002	-.0093	
1485.00	132.8	052369	018384	-0014429	-0005660	.00013	.0000	BRG
1622.50	132.8	052369	000000	-0014305	-0717189	.00009	.0167	
1760.00	115.5	052369	104958	-0032566	-3939545	-.00047	.0000	BRG
1817.00	115.5	052369	-065812	0065812	-0000700	-.00068	-.0349	
1817.01	000.0	000000	000000	- 1	-0000700	-.00068	-.0349	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00644	-00917	00346	-00093	00025	-00007	00002	-00000	00000	0000
N02	-00917	01346	-00585	00197	-00053	00014	-00004	00001	00000	0000
N03	00346	-00585	00435	-00289	00118	-00031	00008	-00001	00000	0000
N04	-00093	00197	-00289	00367	-00271	00113	-00028	00005	00000	0000
N05	00025	-00053	00118	-00271	00361	-00268	00105	-00017	00000	0000
N06	-00007	00014	-00031	00113	-00268	00353	-00239	00065	00000	0000
N07	00002	-00004	00008	-00028	00105	-00239	00249	-00092	00000	0000
N08	-00000	00001	-00001	00005	-00017	00065	-00092	00040	00000	0000

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
32493	64949	36690	36799	35237	41376	18384	/04958	00000	00000

G-2-B

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS	SLOPE RADIANS	DEFLECT. INCHES	
000.00	132.8	052369	000000	0000000		-.00001	.0001	
0018.00	132.8	052369	022938	-0002390	-0021514	-.00001	.0000	BRG
0036.00	392.8	458236	000000	0018157	0326829	-.00000	-.0001	
0064.00	392.8	458236	-030500	0007158	0681234	.00000	-.0001	
0092.00	132.8	052369	000000	-0034342	-0126349	.00000	.0000	
0110.00	132.8	052369	054681	-0036733	-0766020	-.00001	.0000	BRG
0178.75	132.8	052369	000000	0008818	0154053	-.00004	-.0026	
0247.50	132.8	052369	000000	-0000313	0446419	.00000	-.0043	
0316.25	132.8	052369	000000	-0009443	0111079	.00005	-.0024	
0385.00	132.8	052369	036849	-0018573	-0851969	.00000	.0000	BRG
0522.50	132.8	052369	000000	0000015	0405552	-.00000	-.0035	
0660.00	132.8	052369	036757	-0018245	-0847755	-.00000	.0000	BRG
0797.50	132.8	052369	000000	0000251	0442206	-.00000	-.0042	
0935.00	132.8	052369	035250	-0018009	-0778660	.00001	.0000	BRG
1072.50	132.8	052369	000000	-0001020	0336458	.00001	-.0023	
1210.00	132.8	052369	041372	-0019281	-1059252	-.00003	.0000	BRG
1347.50	132.8	052369	000000	0003830	0722797	-.00002	-.0093	
1485.00	132.8	052369	018391	-0014430	-0005981	.00013	.0000	BRG
1622.50	132.8	052369	000000	-0014300	-0716813	.00009	.0167	
1760.00	115.5	052369	104956	-0032561	-3938472	-.00047	.0000	BRG
1817.00	115.5	052369	-065812	0065815	0000517	-.00068	-.0348	
1817.01	000.0	000000	000000	2	0000517	-.00068	-.0349	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00644	-00917	00346	-00093	00025	-00007	00002	-00000	00000	0000
N02	-00917	01346	-00585	00197	-00053	00014	-00004	00001	00000	0000
N03	00346	-00585	00435	-00289	00118	-00031	00008	-00001	00000	0000
N04	-00093	00197	-00289	00367	-00271	00113	-00028	00005	00000	0000
N05	00025	-00053	00118	-00271	00361	-00268	00105	-00017	00000	0000
N06	-00007	00014	-00031	00113	-00268	00353	-00239	00065	00000	0000
N07	00002	-00004	00008	-00028	00105	-00239	00249	-00092	00000	0000
N08	-00000	00001	-00001	00005	-00017	00065	-00092	00040	00000	0000

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
22938	54680	36848	36757	35249	41371	18391	04955	00000	00000

S-1-702

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	054.8	008902	000000	00		.00000	-.0000	
0008.25	054.8	008902	003044	-0000452	-0001863	.00000	.0000	BRG
0016.50	203.1	122495	000000	0002140	0017657	.00000	.0000	
0031.75	203.1	122495	-010998	-0000957	0026678	.00000	.0000	
0047.00	054.8	008902	000000	-0015053	-0179257	.00000	.0001	
0055.25	054.8	008902	021721	-0015504	-0305305	-.00002	-.0000	BRG
0063.50	040.6	004906	000000	0005765	-0255882	-.00005	-.0003	
0209.75	040.6	004906	000000	-0000180	0152523	.00001	-.0175	
0364.25	040.6	004906	013276	-0006460	-0360389	-.00006	.0000	BRG
0518.75	040.6	004906	000000	0000536	0207572	-.00004	-.0309	
0658.27	049¤0	007415	000000	-0005135	-0113244	.00028	-.0039	
0673.25	049¤0	007415	008311	-0005884	-0195773	.00025	.0000	BRG
0688.23	043.4	007415	000000	0001679	-0165020	.00021	.0034	
0772.75	043.4	007415	000000	-0001993	-0178321	.00004	.0143	
0872.25	043.4	007415	025813	-0006316	-0591708	-.00042	.0000	BRG
0903.70	043.4	007415	-018130	0018130	-0000021	-.00055	-.0159	
0903.71	000.0	000000	0	-	- 21	-.00055	-.0159	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00248	-00296	00062	-00020	00006	00000	000			
N02	-00296	00357	-00081	00029	-00008	00000	000			
N03	00062	-00081	00035	-00027	00011	00000	000			
N04	-00020	00029	-00027	00035	-00018	00000	000			
N05	00006	-00008	00011	-00018	00010	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
03043	21720	13275	08310	25812	00000	000	0		

S-1-702-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
.00	054.8	008902	000000			.00000	-.0000	
8.25	054.8	008902	-002418	452	-0001863	.00000	.0000	BRG
16.50	203.1	122495	000000	3322	-0027403	.00000	.0000	
31.75	203.1	122495	000000	6419	-0101675	.00000	.0001	
47.00	054.8	008902	000000	9516	-0223182	.00000	.0001	
55.25	054.8	008902	016178	9968	-0303556	-.00002	-.0000	BRG
63.50	040.6	004906	000000	5758	-0254193	-.00005	-.0003	
209.75	040.6	004906	000000	187	0153157	.00002	-.0176	
364.25	040.6	004906	013285	6467	-0360870	-.00006	.0000	BRG
518.75	040.6	004906	000000	538	0207417	-.00004	-.0308	
658.27	049□0	007415	000000	5133	-0113104	.00028	-.0039	
673.25	049□0	007415	008308	5881	-0195602	.00025	.0000	BRG
688.23	043.4	007415	000000	1678	-0164862	.00021	.0034	
772.75	043.4	007415	000000	1994	-0178236	.00004	.0143	
872.25	043.4	007415	025814	6317	-0591709	-.00042	.0000	BRG
903.70	043.4	007415	-018130	18130	-0000022	-.00055	-.0159	
903.71	000.0	000000	00000		- 22	-.00055	-.0159	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00248	-00296	00062	-00020	00006					
N02	-00296	00357	-00081	00029	-00008					
N03	00062	-00081	00035	-00027	00011					
N04	-00020	00029	-00027	00035	-00018					
N05	00006	-00008	00011	-00018	00010					

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-2418	16177	13285	08307	25813					

S-5-602

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115.8	039795	000000	000		-.00000	.0000	
0011.40	115.8	039795	013097	-0001320	-0007523	-.00000	-.0000	BRG
0022.80	318C2	300649	000000	0010457	0119214	.00000	-.0000	
0043.05	318C2	300649	-034280	0004014	0265735	.00000	.0000	
0063.30	115.8	039795	000000	-0036710	-0412398	.00000	.0001	
0074.70	115.8	039795	053062	-0038030	-0838413	-.00002	-.0000	BRG
0086.10	086.2	022045	000000	0013712	-0674569	-.00004	-.0003	
0247.20	086.2	022045	000000	-0000169	0416377	.00000	-.0137	
0419.70	086C2	022045	030414	-0015032	-0894693	-.00002	-.0000	BRG
0592.20	086C2	022045	000000	0000518	0476649	-.00001	-.0179	
0742.69	107.9	034560	000000	-0012449	-0421076	.00012	-.0022	
0764.70	107.9	034560	028322	-0014823	-0721206	.00008	.0000	BRG
0786.71	093.8	034560	000000	0011124	-0450234	.00004	.0014	
0947.20	093.8	034560	000000	-0003928	0127214	.00006	.0064	
1129.70	093.8	034560	069778	-0021044	-2151495	-.00033	.0000	BRG
1175.90	093.8	034560	-044400	0044401	-0000087	-.00048	-.0198	
1175.91	000C0	000000	0 0	-	- 87	-.00048	-.0198	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00546	-00674	00163	-00043	00008	00000	000	0		
N02	-00674	00839	-00221	00068	-00012	00000	000			
N03	00163	-00221	00105	-00065	00018	00000	000	0		
N04	-00043	00068	-00065	00064	-00023	00000	000			
N05	00008	-00012	00018	-00023	00010	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
13096	53061	30413	28321	69777	00000	000			

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SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115.8	039795	000000	000		.00000	-.0000	
0011.40	115.8	039795	004088	-0001320	-0007523	.00000	-.0000	BRG
0022.80	318.2	300649	000000	0001449	0016514	.00000	.0000	
0043.05	318.2	300649	-034280	-0004995	-0019394	.00000	.0001	
0063.30	115.8	039795	000000	-0045719	-0879955	.00000	.0002	
0074.70	115.8	039795	066548	-0047038	-1408670	-.00003	-.0000	BRG
0086.10	086.2	022045	000000	0018190	-1193778	-.00007	-.0006	
0275.95	086.2	022045	000000	0001832	0706834	-.00006	-.0384	
0455.19	107.9	034560	000000	-0013612	-0348911	.00028	-.0058	
0477.20	107.9	034560	022100	-0015987	-0674647	.00024	-.0000	BRG
0499.21	093.8	034560	000000	0003738	-0566235	.00021	.0049	
0602.20	093.8	034560	000000	-0005921	-0678622	.00004	.0181	
0727.20	093.8	034560	066378	-0017644	-2151443	-.00042	-.0000	BRG
0773.40	093.8	034560	-044400	0044401	-0000031	-.00056	-.0239	
0773.41	000.0	000000	0	-	- 31	-.00056	-.0239	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00498	-00605	00154	-00047	00000	00000				
N02	-00605	00743	-00207	00069	00000	00000				
N03	00154	-00207	00099	-00046	00000	00000				
N04	-00047	00069	-00046	00024	00000	00000				

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
04088	66548	22099	66378	00000	00000				

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22 MAR. 1960

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115.8	039795	000000	000		.00000	-.0000	
0011.40	115.8	039795	008951	-0001320	-0007523	.00000	.0000	BRG
0022.80	318.2	300649	000000	0006311	0071947	.00000	.0000	
0043.05	318.2	300649	-034280	-0000132	0134507	.00000	.0001	
0063.30	115.8	039795	000000	-0040856	-0627587	.00000	.0001	
0074.70	115.8	039795	059380	-0042176	-1100868	-.00002	-.0000	BRG
0086.10	086.2	022045	000000	0015884	-0912265	-.00005	-.0004	
0275.95	086.2	022045	000000	-0000474	0550545	.00001	-.0239	
0477.20	086.2	022045	036560	-0017815	-1289767	-.00006	-.0000	BRG
0678.45	086.2	022045	000000	0001405	0737889	-.00004	-.0412	
0857.69	107.9	034560	000000	-0014039	-0394383	.00028	-.0059	
0879.70	107.9	034560	023973	-0016414	-0729517	.00025	.0000	BRG
0901.71	093.8	034560	000000	0005184	-0589275	.00021	.0050	
1022.70	093.8	034560	000000	-0006163	-0648465	.00003	.0195	
1147.70	093.8	034560	066620	-0017886	-2151542	-.00043	.0000	BRG
1193.90	093.8	034560	-044400	0044401	-0000134	-.00057	-.0244	
1193.91	000.0	000000	0	-	- 134	-.00057	-.0244	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00470	-00565	00122	-00039	00011	00000	000			
N02	-00565	00683	-00160	00057	-00016	00000	000	0		
N03	00122	-00160	00070	-00054	00021	00000	000	0		
N04	-00039	00057	-00054	00070	-00035	00000	000	-		
N05	00011	-00016	00021	-00035	00019	00000	000	0		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
08950	59379	36560	23972	66620	00000	000	0		

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22 MAR. 1960

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115.8	039795	000000	000		.00000	-.0000	
0011.40	115.8	039795	007698	-0001320	-0007523	.00000	-.0000	BRG
0022.80	318.2	300649	000000	0005058	0057664	.00000	.0000	
0043.05	318.2	300649	-034280	-0001385	0094851	.00000	.0001	
0063.30	115.8	039795	000000	-0042109	-0692614	.00000	.0001	
0074.70	115.8	039795	061228	-0043429	-1180179	-.00003	-.0000	BRG
0086.10	086.2	022045	000000	0016479	-0984792	-.00006	-.0005	
0275.95	086.2	022045	000000	0000121	0591003	-.00000	-.0276	
0477.20	086.2	022045	034176	-0017220	-1129539	.00002	-.0000	BRG
0678.45	086.2	022045	000000	-0000385	0537973	.00001	-.0227	
0879.70	086.2	022045	036482	-0017725	-1284317	-.00006	-.0000	BRG
1080.95	086.2	022045	000000	0001416	0745547	-.00004	-.0419	
1260.19	107.9	034560	000000	-0014028	-0384759	.00029	-.0060	
1282.20	107.9	034560	022695	-0016403	-0719651	.00026	-.0000	BRG
1304.21	093.8	034560	000000	0003918	-0607290	.00021	.0051	
1407.20	093.8	034560	000000	-0005741	-0701203	.00004	.0186	
1532.20	093.8	034560	066199	-0017465	-2151600	-.00043	-.0000	BRG
1578.40	093.8	034560	-044400	0044401	-0000191	-.00057	-.0242	
1578.41	000.0	000000	0	-	- 191	-.00057	-.0242	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00469	-00562	00119	-00033	00011	-00003	00000	00000		
N02	-00562	00680	-00155	00048	-00016	00005	00000	00000		
N03	00119	-00155	00064	-00042	00020	-00006	00000	00000		
N04	-00033	00048	-00042	00056	-00052	00022	00000	00000		
N05	00011	-00016	00020	-00052	00075	-00039	00000	00000		
N06	-00003	00005	-00006	00022	-00039	00022	00000	00000		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
07697	61227	34175	36481	22694	66198	00000	00000		

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SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115.8	039795	000000	00		.00001	-.0001	
0011.40	115.8	039795	-001942	-0001320	-0007523	.00001	.0000	BRG
0022.80	318.2	300649	000000	-0004582	-0052233	.00001	.0001	
0043.05	318.2	300649	-034280	-0011025	-0210258	.00000	.0002	
0063.30	115.8	039795	000000	-0051749	-1192935	-.00000	.0002	
0074.70	115.8	039795	075005	-0053069	-1790397	-.00004	.0000	BRG
0086.10	086.2	022045	000000	0020617	-1547846	-.00009	-.0008	
0304.70	086.2	022045	000000	0001781	0900212	-.00007	-.0627	
0512.69	107.9	034560	000000	-0016140	-0593090	.00037	-.0076	
0534.70	107.9	034560	025827	-0018515	-0974471	.00032	-.0000	BRG
0556.71	093.8	034560	000000	0004938	-0839661	.00026	.0063	
0659.70	093.8	034560	000000	-0004722	-0828529	.00004	.0215	
0784.70	093.8	034560	065179	-0016445	-2151432	-.00046	-.0000	BRG
0830.90	093.8	034560	-044400	0044401	-0000019	-.00060	-.0256	
0830.91	000.0	000000	0	-	- 19	-.00060	-.0256	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00440	-00523	00126	-00043	00000	00000				
N02	-00523	00628	-00165	00061	00000	00000				
N03	00126	-00165	00079	-00040	00000	00000				
N04	-00043	00061	-00040	00022	00000	00000				

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-01942	75005	25827	65178	00000	00000				

PROB S-5-802

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115.8	039795	000000	000		.00000	-.0000	
0011.40	115.8	039795	003521	-0001320	-0007523	.00000	.0000	BRG
0022.80	318.2	300649	000000	0000882	0010054	.00000	.0000	
0043.05	318.2	300649	-034280	-0005562	-0037327	.00000	.0001	
0063.30	115.8	039795	000000	-0046285	-0909361	.00000	.0002	
0074.70	115.8	039795	067277	-0047605	-1444536	-.00003	.0000	BRG
0086.10	086.2	022045	000000	0018352	-1227802	-.00007	-.0006	
0304.70	086.2	022045	000000	-0000484	0725193	.00002	-.0415	
0534.70	086.2	022045	041530	-0020302	-1665109	-.00007	.0000	BRG
0764.70	086.2	022045	000000	0001411	0938447	-.00006	-.0672	
0972.69	107.9	034560	000000	-0016510	-0631838	.00038	-.0078	
0994.70	107.9	034560	026384	-0018885	-1021366	.00033	.0000	BRG
1016.71	093.8	034560	000000	0005124	-0882445	.00027	.0065	
1119.70	093.8	034560	000000	-0004535	-0852077	.00003	.0220	
1244.70	093.8	034560	064992	-0016258	-2151634	-.00046	.0000	BRG
1290.90	093.8	034560	-044400	0044401	-0000232	-.00061	-.0259	
1290.91	000.0	000000	0	-	- 232	-.00061	-.0259	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00413	-00485	00094	-00033	00011	00000	000	0		
N02	-00485	00574	-00120	00046	-00016	00000	000	0		
N03	00094	-00120	00048	-00041	00019	00000	000	00		
N04	-00033	00046	-00041	00061	-00034	00000	000	00		
N05	00011	-00016	00019	-00034	00020	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
03521	67276	41530	26384	64991	00000	000	0		

PROB S-5-803

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115.8	039795	000000	00		.00000	-.0000	
0011.40	115.8	039795	002092	-0001320	-0007523	.00000	-.0000	BRG
0022.80	318.2	300649	000000	-0000547	-0006236	.00000	.0000	
0043.05	318.2	300649	-034280	-0006991	-0082555	.00000	.0001	
0063.30	115.8	039795	000000	-0047714	-0983527	.00000	.0002	
0074.70	115.8	039795	069299	-0049034	-1534991	-.00004	.0000	BRG
0086.10	086.2	022045	000000	0018945	-1311493	-.00008	-.0006	
0304.70	086.2	022045	000000	0000110	0771202	-.00000	-.0470	
0534.70	086.2	022045	039154	-0019708	-1482637	.00002	.0000	BRG
0764.70	086.2	022045	000000	-0000372	0710869	.00001	-.0397	
0994.70	086.2	022045	041384	-0020190	-1653732	-.00008	.0000	BRG
1224.70	086.2	022045	000000	0001377	0941924	-.00006	-.0676	
1432.69	107.9	034560	000000	-0016545	-0635504	.00038	-.0079	
1454.70	107.9	034560	026438	-0018919	-1025788	.00033	.0000	BRG
1476.71	093.8	034560	000000	0005144	-0886446	.00027	.0066	
1579.70	093.8	034560	000000	-0004516	-0854105	.00003	.0221	
1704.70	093.8	034560	064973	-0016239	-2151268	-.00047	.0000	BRG
1750.90	093.8	034560	-044400	0044401	0000164	-.00061	-.0259	
1750.91	000.0	000000	0		164	-.00061	-.0259	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00411	-00482	00091	-00025	00009	-00003	00000	00000		
N02	-00482	00570	-00115	00036	-00012	00004	00000	00000		
N03	00091	-00115	00043	-00028	00015	-00005	00000	00000		
N04	-00025	00036	-00028	00038	-00038	00017	00000	00000		
N05	00009	-00012	00015	-00038	00060	-00033	00000	00000		
N06	-00003	00004	-00005	00017	-00033	00020	00000	00000		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
02092	69298	39154	41384	26437	64973	00000	00000		

PROB S-5-901

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115.8	039795	000000	00		.00001	-.0001	
0011.40	115.8	039795	-008749	-0001320	-0007523	.00001	-.0000	BRG
0022.80	318.2	300649	000000	-0011389	-0129830	.00001	.0001	
0043.05	318.2	300649	-034280	-0017832	-0425690	.00001	.0002	
0063.30	115.8	039795	000000	-0058556	-1546203	-.00000	.0003	
0074.70	115.8	039795	084258	-0059876	-2221261	-.00005	.0000	BRG
0086.10	086.2	022045	000000	0023063	-1950822	-.00011	-.0010	
0333.45	086.2	022045	000000	0001750	1117920	-.00009	-.0971	
0570.19	107.9	034560	000000	-0018649	-0882351	.00047	-.0096	
0592.20	107.9	034560	029713	-0021023	-1318937	.00040	-.0000	BRG
0614.21	093.8	034560	000000	0006316	-1153801	.00032	.0079	
0717.20	093.8	034560	000000	-0003344	-1000764	.00003	.0254	
0842.20	093.8	034560	063801	-0015067	-2151435	-.00050	-.0000	BRG
0888.40	093.8	034560	-044400	0044401	-0000023	-.00064	-.0275	
0888.41	000.0	000000	0 0	-	- 23	-.00064	-.0275	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00394	-00461	00107	-00039	00000	00000				
N02	-00461	00543	-00136	00054	00000	00000	0			
N03	00107	-00136	00064	-00035	00000	00000	0			
N04	-00039	00054	-00035	00020	00000	00000				

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-08749	84258	29713	63800	00000	00000				

PROB S-5-902

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115.8	039795	000000	0000		.00001	-.0001	
0011.40	115.8	039795	-002688	-0001320	-0007523	.00001	.0000	BRG
0022.80	318.2	300649	000000	-0005328	-0060734	.00001	.0001	
0043.05	318.2	300649	-034280	-0011771	-0233859	.00000	.0002	
0063.30	115.8	039795	000000	-0052495	-1231636	-.00000	.0002	
0074.70	115.8	039795	075966	-0053815	-1837599	-.00004	.0000	BRG
0086.10	086.2	022045	000000	0020832	-1592597	-.00009	-.0008	
0333.45	086.2	022045	000000	-0000481	0924223	.00002	-.0675	
0592.20	086.2	022045	046460	-0022776	-2084733	-.00009	-.0000	BRG
0850.95	086.2	022045	000000	0001388	1158916	-.00007	-.1032	
1087.69	107.9	034560	000000	-0019010	-0927001	.00049	-.0099	
1109.70	107.9	034560	030285	-0021385	-1371550	.00041	-.0000	BRG
1131.71	093.8	034560	000000	0006526	-1201791	.00033	.0082	
1234.70	093.8	034560	000000	-0003134	-1027125	.00002	.0260	
1359.70	093.8	034560	063591	-0014857	-2151546	-.00051	-.0000	BRG
1405.90	093.8	034560	-044400	0044401	-0000129	-.00065	-.0278	
1405.91	000.0	000000	0		- 129	-.00065	-.0278	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00367	-00425	00075	-00028	00010	00000	000			
N02	-00425	00494	-00093	00038	-00014	00000	000	-		
N03	00075	-00093	00034	-00031	00015	00000	000	00		
N04	-00028	00038	-00031	00051	-00030	00000	000			
N05	00010	-00014	00015	-00030	00018	00000	000	0		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-02688	75965	46459	30284	63591	00000	000	0		

PROB S-5-903

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115.8	039795	000000	00		.00001	-.0001	
0011.40	115.8	039795	-004270	-0001320	-0007523	.00001	-.0000	BRG
0022.80	318.2	300649	000000	-0006910	-0078771	.00001	.0001	
0043.05	318.2	300649	-034280	-0013353	-0283935	.00000	.0002	
0063.30	115.8	039795	000000	-0054077	-1313751	-.00000	.0003	
0074.70	115.8	039795	078131	-0055397	-1937751	-.00005	.0000	BRG
0086.10	086.2	022045	000000	0021415	-1686097	-.00010	-.0008	
0333.45	086.2	022045	000000	0000102	0975052	-.00000	-.0752	
0592.20	086.2	022045	044124	-0022193	-1882924	.00003	.0000	BRG
0850.95	086.2	022045	000000	-0000364	0907301	.00002	-.0648	
1109.70	086.2	022045	046306	-0022659	-2071329	-.00010	.0000	BRG
1368.45	086.2	022045	000000	0001352	1162978	-.00007	-.1038	
1605.19	107.9	034560	000000	-0019046	-0931487	.00049	-.0100	
1627.20	107.9	034560	030342	-0021421	-1376830	.00041	.0000	BRG
1649.21	093.8	034560	000000	0006546	-1206612	.00033	.0082	
1752.20	093.8	034560	000000	-0003113	-1029797	.00002	.0260	
1877.20	093.8	034560	063570	-0014836	-2151609	-.00051	.0000	BRG
1923.40	093.8	034560	-044400	0044401	-0000210	-.00065	-.0278	
1923.41	000.0	000000	0	-	- 210	-.00065	-.0278	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00365	-00422	00072	-00020	00007	-00003	00000	00000		
N02	-00422	00490	-00089	00027	-00010	00004	00000	00000		
N03	00072	-00089	00030	-00020	00011	-00004	00000	00000		
N04	-00020	00027	-00020	00027	-00029	00014	00000	00000		
N05	00007	-00010	00011	-00029	00050	-00029	00000	00000		
N06	-00003	00004	-00004	00014	-00029	00018	00000	00000		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-04270	78131	44123	46306	30341	63569	00000	00000		

PROB. S-5-701-A 15 MAR. 1960

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0.00	115.8	039795	000000	0000000		.00000	-.0000	
0011.40	115.8	039795	005887	-0001320	-0007523	.00000	-.0000	BRG
022.80	318C2	300649	000000	0003248	0037027	.00000	.0000	
0043.05	318.2	300649	-034280	-0003196	0037557	.00000	.0001	
0063.30	115.8	039795	000000	-0043919	-0786566	.00000	.0001	
0074.70	115.8	039795	063892	-0045239	-1294768	-.00003	.0000	BRG
0086.10	086.2	022045	000000	0017334	-1089642	-.00006	-.0005	
0275.95	086C2	022045	000000	0000975	0648340	-.00003	-.0331	
0455.19	107.9	034560	000000	-0014469	-0560947	.00019	-.0038	
0477.20	107.9	034560	030847	-0016843	-0905538	.00015	.0000	BRG
0499.21	093.8	034560	000000	0011629	-0623447	.00010	.0027	
0659.70	093.8	034560	000000	-0003423	0035079	.00005	.0109	
0842.20	093.8	034560	069273	-0020539	-2151432	-.00037	.0000	BRG
0888.40	093.8	034560	-044400	0044401	-0000021	-.00051	-.0213	
0888.41	000.0	000000	000000	-	- 21	-.00051	-.0213	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00485	-00586	00129	-00027	00000	00000	000			
N02	-00586	00715	-00169	00041	00000	00000	000			
N03	00129	-00169	00064	-00023	00000	00000	000			
N04	-00027	00041	-00023	00010	00000	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
5887	63892	30847	69272	00000	00000	000			

PROB. S-5-702-A 15 MAR. 1960

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115.8	039795	000000	0000		.00000	-.0000	
0011.40	115.8	039795	008521	-0001320	-0007523	.00000	-.0000	BRG
0022.80	318.2	300649	000000	0005882	0067049	.00000	.0000	
0043.05	318.2	300649	-034280	-0000562	0120908	.00000	.0001	
0063.30	115.8	039795	000000	-0041286	-0649886	.00000	.0001	
0074.70	115.8	039795	060014	-0042605	-1128065	-.00002	-.0000	BRG
0086.10	086.2	022045	000000	0016089	-0937125	-.00005	-.0005	
0275.95	086.2	022045	000000	-0000269	0564605	.00001	-.0252	
0477.20	086.2	022045	035734	-0017610	-1234450	-.00003	-.0000	BRG
0678.45	086.2	022045	000000	0000784	0668181	-.00002	-.0348	
0857.69	107.9	034560	000000	-0014660	-0575444	.00020	-.0039	
0879.70	107.9	034560	031090	-0017035	-0924251	.00015	-.0000	BRG
0901.71	093.8	034560	000000	0011680	-0641035	.00010	.0028	
1062.20	093.8	034560	000000	-0003372	0025694	.00005	.0113	
1244.70	093.8	034560	069222	-0020488	-2151490	-.00037	-.0000	BRG
1290.90	093.8	034560	-044400	0044401	-0000083	-.00051	-.0215	
1290.91	000.0	000000	0 0	-	- 83	-.00051	-.0215	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00470	-00564	00121	-00034	00007	00000	000	0		
N02	-00564	00682	-00158	00050	-00011	00000	000	00		
N03	00121	-00158	00068	-00044	00014	00000	000	00		
N04	-00034	00050	-00044	00048	-00019	00000	000	00		
N05	00007	-00011	00014	-00019	00009	00000	000	00		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
08521	60014	35734	31089	69221	00000	000	00		

PROB. S-5-703-A

15 MAR. 1960

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0.00	115C8	039795	000000	0000000		.00000	-.0000	
0011.40	115.8	039795	007821	-0001320	-0007523	.00000	-.0000	BRG
022.80	318C2	300649	000000	0005182	0059072	.00000	.0000	
0043.05	318.2	300649	-034280	-0001262	0098761	.00000	.0001	
0063.30	115.8	039795	000000	-0041985	-0686203	.00000	.0001	
0074.70	115.8	039795	061046	-0043305	-1172360	-.00003	-.0000	BRG
0086.10	086.2	022045	000000	0016421	-0977642	-.00006	-.0005	
0275.95	086.2	022045	000000	0000062	0587015	-.00000	-.0273	
0477.20	086C2	022045	034411	-0017278	-1145335	.00001	-.0000	BRG
0678.45	086.2	022045	000000	-0000208	0557762	.00001	-.0245	
0879.70	086C2	022045	035655	-0017548	-1228942	-.00003	-.0000	BRG
1080.95	086C2	022045	000000	0000766	0670064	-.00002	-.0350	
1260.19	107.9	034560	000000	-0014678	-0576788	.00020	-.0039	
1282.20	107C9	034560	031112	-0017053	-0925992	.00015	-.0000	BRG
1304.21	093C8	034560	000000	0011684	-0642689	.00010	.0028	
1464.70	093.8	034560	000000	-0003368	0024673	.00005	.0114	
1647.20	093.8	034560	069217	-0020484	-2151790	-.00037	-.0000	BRG
1693.40	093C8	034560	-044400	0044400	-0000404	-.00051	-.0215	
1693.41	000C0	000000	000000	- 1	-0000404	-.00051	-.0215	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00469	-00562	00119	-00032	00009	-00002	00000	00000	0000	
N02	-00562	00679	-00155	00048	-00013	00003	00000	00000	00000	
N03	00119	-00155	00064	-00041	00017	-00004	00000	00000	00000	
N04	-00032	00048	-00041	00053	-00040	00013	00000	00000	00000	
N05	00009	-00013	00017	-00040	00047	-00019	00000	00000	00000	
N06	-00002	00003	-00004	00013	-00019	00009	00000	00000	00000	

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
7821	61045	34411	35654	31111	69217	00000	00000	00000	

PROB S-5-801-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH KIPS	SLOPE RADIANS	DEFLECT. INCHES	
0.00	115.8	039795	000000	0000000		.00001	-.0001	
0011.40	115.8	039795	-000587	-0001320	-0007523	.00001	-.0000	BRG
022.80	318.2	300649	000000	-0003226	-0036777	.00001	.0001	
043.05	318.2	300649	-034280	-0009670	-0167346	.00000	.0002	
063.30	115.8	039795	000000	-0050393	-1122567	.00000	.0002	
0074.70	115.8	039795	073085	-0051713	-1704573	-.00004	.0000	BRG
086.10	086.2	022045	000000	0020053	-1468451	-.00009	-.0007	
0304.70	086.2	022045	000000	0001217	0856317	-.00005	-.0574	
0512.69	107.9	034560	000000	-0016704	-0754290	.00029	-.0058	
0534.70	107.9	034560	033747	-0019079	-1148085	.00023	.0000	BRG
0556.71	093.8	034560	000000	0012294	-0851365	.00017	.0044	
0717.20	093.8	034560	000000	-0002758	-0086169	.00004	.0167	
0899.70	093.8	034560	068607	-0019874	-2151381	-.00041	.0000	BRG
0945.90	093.8	034560	-044400	0044400	-0000012	-.00055	-.0233	
0945.90	000.0	000000	000000	-	- 12	-.00055	-.0233	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00429	-00508	00105	-00025	00000	00000	0			
N02	-00508	00606	-00134	00036	00000	00000	000			
N03	00105	-00134	00049	-00019	00000	00000	000			
N04	-00025	00036	-00019	00009	00000	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
- 586	73085	33747	68607	00000	00000	000			

PROB S-5-802-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH KIPS	SLOPE RADIANS	DEFLECT. INCHES	
.00	115.8	039795	000000	0000000		.00000	-.0000	
0011.40	115.8	039795	003178	-0001320	-0007523	.00000	.0000	BRG
022.80	318.2	300649	000000	0000538	0006138	.00000	.0000	
043.05	318.2	300649	-034280	-0005905	-0048201	.00000	.0001	
063.30	115.8	039795	000000	-0046629	-0927192	.00000	.0002	
0074.70	115.8	039795	067763	-0047949	-1466283	-.00003	.0000	BRG
0086.10	086.2	022045	000000	0018495	-1247923	-.00007	-.0006	
0304.70	086.2	022045	000000	-0000341	0736254	.00001	-.0428	
0534.70	086.2	022045	040957	-0020159	-1621240	-.00005	.0000	BRG
0764.70	086.2	022045	000000	0000980	0883323	-.00004	-.0606	
0972.69	107.9	034560	000000	-0016941	-0776483	.00030	-.0060	
0994.70	107.9	034560	034058	-0019315	-1175484	.00024	.0000	BRG
1016.71	093.8	034560	000000	0012368	-0877130	.00018	.0046	
1177.20	093.8	034560	000000	-0002684	-0100014	.00004	.0174	
1359.70	093.8	034560	068534	-0019800	-2151673	-.00041	.0000	BRG
1405.90	093.8	034560	-044400	0044401	-0000275	-.00056	-.0235	
1405.91	000.0	000000	000000	-	- 275	-.00056	-.0235	

PROB S-5-802-A

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00412	-00484	00093	-00027	00007	00000	000-	000		
N02	-00484	00572	-00118	00039	-00009	00000	0000	000		
N03	00093	-00118	00046	-00032	00011	00000	0000	000		
N04	-00027	00039	-00032	00037	-00017	00000	0000	000 0		
N05	00007	-00009	00011	-00017	00008	00000	0000	000 0		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
3177	67762	40957	34058	68533	00000	0000	000		

PROB S-5-803-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH KIPS	SLOPE RADIANS	DEFLECT. INCHES	
.00	115.8	039795	000000	0000000		.00000	-.0000	
0011.40	115.8	039795	002184	-0001320	-0007523	.00000	-.0000	BRG
022.80	318.2	300649	000000	-0000455	-0005192	.00000	.0000	
043.05	318.2	300649	-034280	-0006899	-0079656	.00000	.0001	
063.30	115.8	039795	000000	-0047623	-0978772	.00000	.0002	
0074.70	115.8	039795	069169	-0048942	-1529193	-.00004	-.0000	BRG
086.10	086.2	022045	000000	0018907	-1306129	-.00008	-.0006	
0304.70	086.2	022045	000000	0000072	0768252	-.00000	-.0467	
0534.70	086.2	022045	039307	-0019746	-1494334	.00002	.0000	BRG
0764.70	086.2	022045	000000	-0000257	0725518	.00001	-.0415	
0994.70	086.2	022045	040849	-0020075	-1612739	-.00006	.0000	BRG
1224.70	086.2	022045	000000	0000956	0886099	-.00004	-.0609	
1432.69	107.9	034560	000000	-0016966	-0778884	.00030	-.0061	
1454.70	107.9	034560	034092	-0019340	-1178433	.00024	.0000	BRG
1476.71	093.8	034560	000000	0012377	-0879887	.00018	.0046	
1637.20	093.8	034560	000000	-0002675	-0101378	.00004	.0174	
1819.70	093.8	034560	068525	-0019791	-2151451	-.00041	.0000	BRG
1865.90	093.8	034560	-044400	0044401	-0000049	-.00056	-.0235	
1865.91	000.0	000000	000000	-	- 49	-.00056	-.0235	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00411	-00482	00091	-00025	00007	-00002	00000	00000	00 0	
N02	-00482	00570	-00115	00035	-00010	00003	00000	00000	0000	
N03	00091	-00115	00043	-00028	00012	-00003	00000	00000	0000	
N04	-00025	00035	-00028	00036	-00029	00010	00000	00000	00	
N05	00007	-00010	00012	-00029	00037	-00016	00000	00000	00 0	
N06	-00002	00003	-00003	00010	-00016	00008	00000	00000	0000	

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
2184	69169	39306	40848	34091	68525	00000	00000	0000	

PROB S-5-901-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH KIPS	SLOPE RADIANS	DEFLECT. INCHES	
0.00	115.8	039795	000000	0000000		.00001	-.0001	
0011.40	115.8	039795	-007818	-0001320	-0007523	.00001	-.0000	BRG
022.80	318.2	300649	000000	-0010458	-0119218	.00001	.0001	
043.05	318.2	300649	-034280	-0016901	-0396228	.00001	.0002	
063.30	115.8	039795	000000	-0057625	-1497891	-.00000	.0003	
0074.70	115.8	039795	082983	-0058945	-2162337	-.00005	.0000	BRG
0086.10	086.2	022045	000000	0022719	-1895818	-.00011	-.0009	
0333.45	086.2	022045	000000	0001406	1087870	-.00007	-.0925	
0570.19	107.9	034560	000000	-0018992	-0993808	.00041	-.0083	
0592.20	107.9	034560	036829	-0021367	-1437962	.00033	.0000	BRG
0614.21	093.8	034560	000000	0013088	-1123766	.00025	.0064	
0774.70	093.8	034560	000000	-0001964	-0231132	.00003	.0237	
0957.20	093.8	034560	067814	-0019080	-2151430	-.00046	.0000	BRG
1003.40	093.8	034560	-044400	0044401	-0000018	-.00060	-.0256	
1003.41	000.0	000000	000000	-	- 18	-.00060	-.0256	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00384	-00448	00087	-00024	00000	00000	0			
N02	-00448	00526	-00110	00032	00000	00000	00			
N03	00087	-00110	00040	-00017	00000	00000	00			
N04	-00024	00032	-00017	00008	00000	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
- 7818	82983	36829	67814	00000	00000	000			

PROB S-5-902-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH KIPS	SLOPE RADIANS	DEFLECT. INCHES	
00.00	115.8	039795	000000	0000000		.00001	-.0001	
0011.40	115.8	039795	-002919	-0001320	-0007523	.00001	.0000	BRG
0022.80	318.2	300649	000000	-0005558	-0063363	.00001	.0001	
0043.05	318.2	300649	-034280	-0012002	-0241156	.00000	.0002	
0063.30	115.8	039795	000000	-0052725	-1243602	-.00000	.0002	
0074.70	115.8	039795	076281	-0054045	-1852193	-.00004	.0000	BRG
0086.10	086.2	022045	000000	0020917	-1606222	-.00009	-.0008	
0333.45	086.2	022045	000000	-0000396	0931630	.00002	-.0686	
0592.20	086.2	022045	046118	-0022691	-2055326	-.00007	-.0000	BRG
0850.95	086.2	022045	000000	0001132	1121999	-.00006	-.0976	
1087.69	107.9	034560	000000	-0019267	-1024602	.00043	-.0086	
1109.70	107.9	034560	037204	-0021641	-1474793	.00035	-.0000	BRG
1131.71	093.8	034560	000000	0013188	-1158389	.00026	.0067	
1292.20	093.8	034560	000000	-0001864	-0249662	.00003	.0246	
1474.70	093.8	034560	067714	-0018980	-2151659	-.00047	-.0000	BRG
1520.90	093.8	034560	-044400	0044401	-0000260	-.00061	-.0259	
1520.91	000.0	000000	000000	-	- 260	-.00061	-.0259	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00367	-00424	00074	-00023	00006	00000	0000	00^		
N02	-00424	00492	-00091	00031	-00008	00000	0000	000		
N03	00074	-00091	00033	-00024	00009	00000	0000	000 ^		
N04	-00023	00031	-00024	00030	-00014	00000	0000	000 ^		
N05	00006	-00008	00009	-00014	00008	00000	0000	000 ^		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
- 2918	76281	46118	37203	67713	00000	0000	000 ^		

PROB S-5-903 -A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH KIPS	SLOPE RADIANS	DEFLECT. INCHES	
0.00	115.8	039795	000000	0000000		.00001	-.0001	
0011.40	115.8	039795	-004209	-0001320	-0007523	.00001	-.0000	BRG
-022.80	318.2	300649	000000	-0006848	-0078071	.00001	.0001	
0043.05	318.2	300649	-034280	-0013292	-0281992	.00000	.0002	
063.30	115.8	039795	000000	-0054016	-1310566	-.00000	.0003	
0074.70	115.8	039795	078047	-0055335	-1933866	-.00005	-.0000	BRG
0086.10	086.2	022045	000000	0021392	-1682470	-.00010	-.0008	
0333.45	086.2	022045	000000	0000080	0973080	-.00000	-.0749	
0592.20	086.2	022045	044215	-0022215	-1890753	.00002	-.0000	BRG
0850.95	086.2	022045	000000	-0000296	0917098	.00001	-.0663	
1109.70	086.2	022045	045988	-0022591	-2043905	-.00008	-.0000	BRG
1368.45	086.2	022045	000000	0001102	1125651	-.00006	-.0982	
1605.19	107.9	034560	000000	-0019297	-1028057	.00043	-.0086	
1627.20	107.9	034560	037246	-0021671	-1478909	.00035	-.0000	BRG
1649.21	093.8	034560	000000	0013200	-1162234	.00026	.0067	
1809.70	093.8	034560	000000	-0001851	-0251535	.00003	.0247	
1992.20	093.8	034560	067701	-0018968	-2151289	-.00047	-.0000	BRG
2038.40	093.8	034560	-044400	0044401	0000117	-.00061	-.0260	
2038.41	000.0	000000	000000	-	117	-.00061	-.0260	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00365	-00422	00072	-00020	00006	-00002	00000	00000	0000	
N02	-00422	00490	-00089	00027	-00008	00002	00000	00000	0000	
N03	00072	-00089	00030	-00020	00009	-00002	00000	00000	0000	
N04	-00020	00027	-00020	00026	-00022	00009	00000	00000	0000	
N05	00006	-00008	00009	-00022	00030	-00014	00000	00000	0000	
N06	-00002	00002	-00002	00009	-00014	00008	00000	00000	0000	

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
- 4208	78047	44214	45988	37246	67701	00000	00000	0000	

S-5-SP602

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115C8	039795	000000	0000		.00001	-.0001	
0011.40	115C8	039795	000353	-0001320	-0007523	.00001	.0000	BRG
0022.80	318C2	300649	000000	-0002286	-0026063	.00000	.0001	
0043.05	318C2	300649	-034280	-0008730	-0137601	.00000	.0001	
0063.30	115C8	039795	000000	-0049453	-1073791	.00000	.0002	
0074.70	115C8	039795	074653	-0050773	-1645083	-.00004	-.0000	BRG
0086.10	110C9	036548	000000	0022560	-1380381	-.00008	-.0007	
0299.70	110C9	036548	000000	-0001138	0907411	.00003	-.0304	
0524.70	110C9	036548	053723	-0026101	-2157009	-.00007	-.0000	BRG
0749.70	110C9	036548	000000	0002659	1249615	-.00006	-.0541	
0952.69	107C9	034560	000000	-0019862	-0496336	.00036	-.0075	
0974.70	107C9	034560	029489	-0022236	-0959621	.00031	-.0000	BRG
0996.71	093C8	034560	000000	0004878	-0826121	.00026	.0063	
1099.70	093C8	034560	000000	-0004781	-0821121	.00004	.0213	
1224.70	093C8	034560	065238	-0016504	-2151466	-.00046	-.0000	BRG
1270.90	093C8	034560	-044400	0044401	-0000056	-.00060	-.0255	
1270.91	000C0	000000	0 0	-	- 56	-.00060	-.0255	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00656	-00774	00150	-00047	00014	00000	000			
N02	-00774	00919	-00192	00068	-00020	00000	000			
N03	00150	-00192	00077	-00060	00025	00000	000			
N04	-00047	00068	-00060	00086	-00046	00000	000			
N05	00014	-00020	00025	-00046	00027	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
00353	74652	53722	29488	65238	00000	000			

S-5-SP702

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115C8	039795	000000	0000		.00001	-.0001	
0011.40	115C8	039795	-009551	-0001320	-0007523	.00001	-.0000	BRG
0022.80	318C2	300649	000000	-0012190	-0138971	.00001	.0001	
0043.05	318C2	300649	-034280	-0018634	-0451069	.00001	.0002	
0063.30	115C8	039795	000000	-0059358	-1587820	-.00000	.0003	
0074.70	115C8	039795	088680	-0060677	-2272019	-.00006	-.0000	BRG
0086.10	110C9	036548	000000	0026683	-1960313	-.00012	-.0010	
0337.20	110C9	036548	000000	-0001176	1242122	.00004	-.0571	
0599.70	110C9	036548	062139	-0030299	-2888869	-.00010	.0000	BRG
0862.20	110C9	036548	000000	0002717	1646794	-.00009	-.0952	
1102.69	107C9	034560	000000	-0023964	-0908039	.00051	-.0105	
1124.70	107C9	034560	035599	-0026339	-1461620	.00043	.0000	BRG
1146.71	093C8	034560	000000	0006886	-1283937	.00035	.0086	
1249.70	093C8	034560	000000	-0002774	-1072195	.00002	.0270	
1374.70	093C8	034560	063231	-0014497	-2151615	-.00052	.0000	BRG
1420.90	093C8	034560	-044400	0044401	-0000208	-.00066	-.0283	
1420.91	000C0	000000	0 0	-	- 208	-.00066	-.0283	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00568	-00656	00112	-00038	00013	00000	000	0		
N02	-00656	00760	-00139	00052	-00018	00000	000			
N03	00112	-00139	00050	-00043	00020	00000	000			
N04	-00038	00052	-00043	00068	-00039	00000	000			
N05	00013	-00018	00020	-00039	00024	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-09550	88679	62138	35598	63230	00000	000	0		

S-5-SP902

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	115C8	039795	000000	0000		.00002	-.0002	
0011.40	115C8	039795	-034266	-0001320	-0007523	.00002	.0000	BRG
0022.80	318C2	300649	000000	-0036905	-0420720	.00002	.0002	
0043.05	318C2	300649	-034280	-0043349	-1233294	.00001	.0005	
0063.30	115C8	039795	000000	-0084072	-2870521	-.00000	.0006	
0074.70	115C8	039795	121656	-0085392	-3836469	-.00010	.0000	BRG
0086.10	110C9	036548	000000	0034944	-3430591	-.00020	-.0017	
0412.20	110C9	036548	000000	-0001236	2065478	.00006	-.1578	
0749.70	110C9	036548	078957	-0038680	-4670241	-.00017	-.0000	BRG
1087.20	110C9	036548	000000	0002834	2604843	-.00015	-.2418	
1402.69	107C9	034560	000000	-0032168	-2022529	.00090	-.0182	
1424.70	107C9	034560	048982	-0034543	-2756685	.00075	-.0000	BRG
1446.71	093C8	034560	000000	0012065	-2465001	.00058	.0146	
1549.70	093C8	034560	000000	0002406	-1719822	-.00002	.0416	
1674.70	093C8	034560	058051	-0009318	-2151805	-.00067	-.0000	BRG
1720.90	093C8	034560	-044400	0044401	-0000403	-.00082	-.0355	
1720.91	000C0	000000	0 0	-	- 403	-.00082	-.0355	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00448	-00502	00069	-00027	00011	00000	000			
N02	-00502	00564	-00082	00035	-00014	00000	000			
N03	00069	-00082	00024	-00024	00013	00000	000			
N04	-00027	00035	-00024	00047	-00031	00000	000			
N05	00011	-00014	00013	-00031	00021	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-34265	/21655	78957	48982	58051	00000	000	0		

S-6-602

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000	00		-.00000	.0000	
0013.50	162¤0	078843	018888	-0002200	-0014849	-.00000	.0000	BRG
0027.00	417C5	517659	000000	0014488	0195587	.00000	-.0000	
0050.12	417C5	517659	-048650	0004834	0418954	.00000	.0000	
0073.24	162¤0	078843	000000	-0053469	-0705656	.00000	.0001	
0086.74	162D0	078843	079189	-0055669	-1442336	-.00002	.0000	BRG
0100.24	122C2	044304	000000	0021320	-1139663	-.00004	-.0004	
0281.24	122C2	044304	000000	-0000789	0718443	.00001	-.0143	
0475.74	122C2	044304	050669	-0024547	-1745464	-.00004	-.0000	BRG
0670.24	122C2	044304	000000	0002364	1024860	-.00003	-.0274	
0838.47	153C7	070135	000000	-0018185	-0305915	.00021	-.0053	
0864.74	153C7	070135	031406	-0022222	-0836669	.00019	-.0000	BRG
0891.01	133C6	070135	000000	0005146	-0648454	.00016	.0046	
1009.24	133C6	070135	000000	-0010650	-0973843	.00005	.0180	
1153.74	133C6	070135	104433	-0029956	-3907671	-.00040	-.0000	BRG
1208.94	133C6	070135	-067100	0067101	-0000136	-.00055	-.0278	
1208.95	000C0	000000	0	-	- 136	-.00055	-.0278	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00726	-00901	00225	-00069	00018	00000	000	0		
N02	-00901	01129	-00308	00108	-00028	00000	000	0		
N03	00225	-00308	00155	-00113	00041	00000	000	0		
N04	-00069	00108	-00113	00137	-00064	00000	000	0		
N05	00018	-00028	00041	-00064	00033	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
18887	79189	50669	31405	/04432	00000	000	0		

S-6-701

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162□0	078843	000000	00		.00000	-.0001	
0013.50	162□0	078843	004074	-0002200	-0014849	.00000	-.0000	BRG
0027.00	417.5	517659	000000	-0000326	-0004395	.00000	.0001	
0050.12	417.5	517659	-048650	-0009979	-0123516	.00000	.0002	
0073.24	162□0	078843	000000	-0068283	-1590613	.00000	.0002	
0086.74	162□0	078843	101623	-0070482	-2527275	-.00003	-.0000	BRG
0100.24	122.2	044304	000000	0028941	-2121722	-.00007	-.0007	
0313.74	122.2	044304	000000	0002862	1273248	-.00006	-.0438	
0514.47	153.7	070135	000000	-0021657	-0613138	.00028	-.0070	
0540.74	153.7	070135	036257	-0025695	-1235104	.00025	-.0000	BRG
0567.01	133.6	070135	000000	0006525	-1010664	.00020	.0059	
0685.24	133.6	070135	000000	-0009271	-1173022	.00005	.0209	
0829.74	133.6	070135	103054	-0028577	-3907592	-.00043	-.0000	BRG
0884.94	133.6	070135	-067100	0067101	-0000051	-.00058	-.0293	
0884.95	000.0	000000	0	-	- 51	-.00058	-.0293	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00660	-00806	00208	-00062	00000	00000				
N02	-00806	00995	-00281	00092	00000	00000				
N03	00208	-00281	00136	-00062	00000	00000				
N04	-00062	00092	-00062	00032	00000	00000				

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
04074	01623	36256	103053	00000	00000	-			

S-6-702

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000	00		.00000	-.0000	
0013.50	162¤0	078843	011557	-0002200	-0014849	.00000	-.0000	BRG
0027.00	417.5	517659	000000	0007158	0096631	.00000	.0000	
0050.12	417.5	517659	-048650	-0002496	0150525	.00000	.0001	
0073.24	162¤0	078843	000000	-0060799	-1143556	.00000	.0001	
0086.74	162¤0	078843	090495	-0062999	-1979193	-.00003	-.0000	BRG
0100.24	122.2	044304	000000	0025296	-1622846	-.00006	-.0006	
0313.74	122.2	044304	000000	-0000783	0993951	.00002	-.0274	
0540.74	122.2	044304	058521	-0028511	-2330897	-.00006	-.0000	BRG
0767.74	122.2	044304	000000	0002282	1334325	-.00004	-.0472	
0968.47	153.7	070135	000000	-0022237	-0668416	.00029	-.0072	
0994.74	153C7	070135	037080	-0026274	-1305610	.00026	-.0000	BRG
1021.01	133.6	070135	000000	0006769	-1074762	.00021	.0061	
1139.24	133.6	070135	000000	-0009027	-1208278	.00004	.0214	
1283.74	133.6	070135	102810	-0028333	-3907599	-.00043	.0000	BRG
1338.94	133.6	070135	-067100	0067101	-0000053	-.00059	-.0296	
1338.95	000.0	000000	0		- 53	-.00059	-.0296	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00624	-00753	00166	-00054	00016	00000	000			
N02	-00753	00916	-00219	00081	-00024	00000	000			
N03	00166	-00219	00099	-00078	00032	00000	000			
N04	-00054	00081	-00078	00105	-00053	00000	000			
N05	00016	-00024	00032	-00053	00029	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
11557	90494	58521	37080	102809	00000	000	0		

S-6-703

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000	00		.00000	-.0000	
0013.50	162¤0	078843	009592	-0002200	-0014849	.00000	-.0000	BRG
0027.00	417.5	517659	000000	0005192	0070092	.00000	.0000	
0050.12	417.5	517659	-048650	-0004461	0078538	.00000	.0001	
0073.24	162¤0	078843	000000	-0062765	-1260994	.00000	.0002	
0086.74	162¤0	078843	093419	-0064965	-2123169	-.00003	-.0000	BRG
0100.24	122.2	044304	000000	0026255	-1753880	-.00006	-.0006	
0313.74	122.2	044304	000000	0000176	1067582	-.00000	-.0317	
0540.74	122.2	044304	054679	-0027552	-2039659	.00002	-.0000	BRG
0767.74	122.2	044304	000000	-0000601	0970989	.00001	-.0260	
0994.74	122.2	044304	058284	-0028329	-2312636	-.00006	.0000	BRG
1221.74	122.2	044304	000000	0002227	1340033	-.00004	-.0476	
1422.47	153.7	070135	000000	-0022292	-0673808	.00029	-.0073	
1448.74	153.7	070135	037160	-0026330	-1312455	.00026	.0000	BRG
1475.01	133.6	070135	000000	0006793	-1080965	.00021	.0061	
1593.24	133.6	070135	000000	-0009003	-1211591	.00004	.0215	
1737.74	133.6	070135	102786	-0028309	-3907381	-.00043	.0000	BRG
1792.94	133.6	070135	-067100	0067102	0000205	-.00059	-.0296	
1792.95	000.0	000000	00 0	1	0000205	-.00059	-.0296	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00622	-00749	00162	-00044	00015	-00004	00000	00000		
N02	-00749	00910	-00212	00066	-00022	00006	00000	00000		
N03	00162	-00212	00089	-00059	00028	-00008	00000	00000		
N04	-00044	00066	-00059	00079	-00071	00030	00000	00000		
N05	00014	-00022	00028	-00071	00102	-00052	00000	00000		
N06	-00004	00006	-00008	00030	-00052	00029	00000	00000		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
09591	93419	54679	58284	37160	02786	00000	00000		

S-6-801

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000	0		.00001	-.0001	
0013.50	162¤0	078843	-005350	-0002200	-0014849	.00001	.0000	BRG
0027.00	417.5	517659	000000	-0009749	-0131616	.00001	.0001	
0050.12	417.5	517659	-048650	-0019403	-0468615	.00001	.0002	
0073.24	162¤0	078843	000000	-0077706	-2153590	-.00000	.0003	
0086.74	162¤0	078843	114947	-0079906	-3217474	-.00005	-.0000	BRG
0100.24	122.2	044304	000000	0032841	-2759265	-.00010	-.0010	
0346.24	122.2	044304	000000	0002793	1623714	-.00007	-.0716	
0579.47	153.7	070135	000000	-0025697	-1047239	.00037	-.0091	
0605.74	153.7	070135	042165	-0029734	-1775318	.00032	.0000	BRG
0632.01	133.6	070135	000000	0008394	-1501775	.00026	.0076	
0750.24	133.6	070135	000000	-0007402	-1443138	.00004	.0249	
0894.74	133.6	070135	101184	-0026708	-3907611	-.00047	.0000	BRG
0949.94	133.6	070135	-067100	0067101	-0000072	-.00062	-.0313	
0949.95	000.0	000000	0 &	-	- 72	-.00062	-.0313	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00583	-00697	00171	-00057	00000	00000				
N02	-00697	00840	-00224	00081	00000	00000				
N03	00171	-00224	00107	-00053	00000	00000				
N04	-00057	00081	-00053	00029	00000	00000				

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-05349	/14947	42165	/01184	00000	00000				

S-6-802

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000	0		.00000	-.0001	
0013.50	162¤0	078843	003043	-0002200	-0014849	.00000	.0000	BRG
0027.00	417.5	517659	000000	-0001357	-0018316	.00000	.0001	
0050.12	417.5	517659	-048650	-0011010	-0161279	.00000	.0002	
0073.24	162¤0	078843	000000	-0069314	-1652218	.00000	.0002	
0086.74	162¤0	078843	102983	-0071514	-2602802	-.00004	.0000	BRG
0100.24	122.2	044304	000000	0029270	-2192811	-.00008	-.0008	
0346.24	122.2	044304	000000	-0000779	1311535	.00002	-.0477	
0605.74	122.2	044304	066409	-0032477	-3003466	-.00007	.0000	BRG
0865.24	122.2	044304	000000	0002234	1688995	-.00006	-.0765	
1098.47	153.7	070135	000000	-0026255	-1112287	.00039	-.0095	
1124.74	153.7	070135	043000	-0030293	-1855046	.00033	.0000	BRG
1151.01	133.6	070135	000000	0008669	-1574271	.00027	.0078	
1269.24	133.6	070135	000000	-0007127	-1483083	.00004	.0255	
1413.74	133.6	070135	100909	-0026433	-3907773	-.00047	.0000	BRG
1468.94	133.6	070135	-067100	0067101	-0000247	-.00062	-.0316	
1468.95	000.0	000000	0	-	- 247	-.00062	-.0316	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00548	-00646	00128	-00044	00015	00000	000			
N02	-00646	00768	-00164	00063	-00021	00000	000			
N03	00128	-00164	00067	-00057	00025	00000	000			
N04	-00044	00063	-00057	00083	-00045	00000	000	-		
N05	00015	-00021	00025	-00045	00027	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
03042	/02983	66408	42999	/00908	00000	000			

S-6-803

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000	0		.00001	-.0001	
0013.50	162¤0	078843	000845	-0002200	-0014849	.00001	.0000	BRG
0027.00	417.5	517659	000000	-0003554	-0047983	.00000	.0001	
0050.12	417.5	517659	-048650	-0013208	-0241752	.00000	.0002	
0073.24	162¤0	078843	000000	-0071511	-1783498	-.00000	.0002	
0086.74	162¤0	078843	106118	-0073711	-2763748	-.00004	.0000	BRG
0100.24	122.2	044304	000000	0030207	-2341108	-.00008	-.0008	
0346.24	122.2	044304	000000	0000158	1393750	-.00000	-.0539	
0605.74	122.2	044304	062654	-0031540	-2678089	.00002	.0000	BRG
0865.24	122.2	044304	000000	-0000584	1283242	.00001	-.0454	
1124.74	122.2	044304	066154	-0032282	-2981047	-.00008	.0000	BRG
1384.24	122.2	044304	000000	0002174	1695898	-.00006	-.0770	
1617.47	153.7	070135	000000	-0026315	-1119330	.00039	-.0095	
1643.74	153.7	070135	043089	-0030353	-1863660	.00033	.0000	BRG
1670.01	133.6	070135	000000	0008699	-1582095	.00027	.0079	
1788.24	133.6	070135	000000	-0007097	-1487358	.00004	.0256	
1932.74	133.6	070135	100879	-0026403	-3907709	-.00047	.0000	BRG
1987.94	133.6	070135	-067100	0067101	-0000167	-.00062	-.0317	
1987.95	000.0	000000	0	-	- 167	-.00062	-.0317	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00545	-00643	00124	-00034	00012	-00004	00000	00000		
N02	-00643	00763	-00158	00049	-00017	00006	00000	00000		
N03	00124	-00158	00060	-00040	00020	-00007	00000	00000		
N04	-00034	00049	-00040	00053	-00052	00024	00000	00000		
N05	00012	-00017	00020	-00052	00082	-00045	00000	00000		
N06	-00004	00006	-00007	00024	-00045	00026	00000	00000		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
00845	/06117	62654	66153	43089	/00879	00000	00000		

S-6-901

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162□0	078843	000000			.00001	-.0002	
0013.50	162□0	078843	-015987	-0002200	-0014849	.00001	.0000	BRG
0027.00	417.5	517659	000000	-0020387	-0275225	.00001	.0001	
0050.12	417.5	517659	-048650	-0030041	-0858168	.00001	.0003	
0073.24	162□0	078843	000000	-0088344	-2789087	-.00000	.0004	
0086.74	162□0	078843	129514	-0090544	-3996580	-.00006	.0000	BRG
0100.24	122.2	044304	000000	0036771	-3485328	-.00012	-.0012	
0378.74	122.2	044304	000000	0002752	2018166	-.00009	-.1111	
0644.47	153.7	070135	000000	-0029707	-1563259	.00048	-.0117	
0670.74	153.7	070135	048326	-0033745	-2396697	.00041	.0000	BRG
0697.01	133.6	070135	000000	0010544	-2066672	.00032	.0095	
0815.24	133.6	070135	000000	-0005252	-1753837	.00003	.0296	
0959.74	133.6	070135	099034	-0024558	-3907629	-.00051	.0000	BRG
1014.94	133.6	070135	-067100	0067101	-0000090	-.00066	-.0337	
1014.95	000.0	000000	0	-	- 90	-.00066	-.0337	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00522	-00614	00143	-00052	00000	00000				
N02	-00614	00726	-00185	00072	00000	00000				
N03	00143	-00185	00088	-00047	00000	00000				
N04	-00052	00072	-00047	00027	00000	00000				

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
—15987	/29514	48326	99034	00000	00000	0			

S-6-902

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000	0-		.00001	-.0001	
0013.50	162¤0	078843	-006645	-0002200	-0014849	.00001	.0000	BRG
0027.00	417.5	517659	000000	-0011045	-0149107	.00001	.0001	
0050.12	417.5	517659	-048650	-0020698	-0516060	.00001	.0002	
0073.24	162¤0	078843	000000	-0079002	-2230990	-.00000	.0003	
0086.74	162¤0	078843	116642	-0081202	-3312364	-.00005	.0000	BRG
0100.24	122.2	044304	000000	0033241	-2848766	-.00010	-.0010	
0378.74	122.2	044304	000000	-0000778	1671640	.00003	-.0775	
0670.74	122.2	044304	074319	-0036446	-3763084	-.00009	.0000	BRG
0962.74	122.2	044304	000000	0002205	2088261	-.00007	-.1177	
1228.47	153.7	070135	000000	-0030254	-1638481	.00049	-.0120	
1254.74	153C7	070135	049182	-0034291	-2486285	.00042	.0000	BRG
1281.01	133.6	070135	000000	0010853	-2148133	.00033	.0098	
1399.24	133.6	070135	000000	-0004943	-1798718	.00002	.0302	
1543.74	133.6	070135	098725	-0024249	-3907803	-.00052	.0000	BRG
1598.94	133.6	070135	-067100	0067101	-0000264	-.00067	-.0340	
1598.95	000.0	000000	0 0	-	- 264	-.00067	-.0340	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00488	-00566	00102	-00037	00014	00000	000			
N02	-00566	00660	-00127	00051	-00019	00000	000			
N03	00102	-00127	00048	-00043	00021	00000	000			
N04	-00037	00051	-00043	00069	-00040	00000	000			
N05	00014	-00019	00021	-00040	00024	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-06645	16642	74318	49182	98725	00000	000	0		

S-6-903

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000	0		.00001	-.0001	
0013.50	162¤0	078843	-009087	-0002200	-0014849	.00001	.0000	BRG
0027.00	417.5	517659	000000	-0013487	-0182071	.00001	.0001	
0050.12	417.5	517659	-048650	-0023140	-0605477	.00001	.0003	
0073.24	162¤0	078843	000000	-0081444	-2376860	-.00000	.0003	
0086.74	162¤0	078843	120008	-0083643	-3491198	-.00005	.0000	BRG
0100.24	122.2	044304	000000	0034165	-3015120	-.00011	-.0011	
0378.24	122.2	044304	000000	0000207	1762657	-.00001	-.0862	
0670.74	122.2	044304	070616	-0035522	-3402039	.00003	.0000	BRG
0962.74	122.2	044304	000000	-0 00573	1638182	.00002	-.0741	
1254.74	122.2	044304	074050	-0036241	-3736607	-.00010	.0000	BRG
1546.74	122.2	044304	000000	0002142	2096284	-.00007	-.1185	
1812.47	153.7	070135	000000	-0030317	-1647252	.00050	-.0121	
1838.74	153C7	070135	049281	-0034355	-2496716	.00042	.0000	BRG
1865.01	133.6	070135	000000	0010889	-2157624	.00033	.0098	
1983.24	133C6	070135	000000	-0004907	-1803982	.00002	.0303	
2127.74	133.6	070135	098690	-0024213	-3907900	-.00052	.0000	BRG
2182.94	133.6	070135	-067100	0067102	-0000338	-.00067	-.0341	
2182.95	000.0	000000	0		- 338	-.00067	-.0341	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00485	-00562	00098	-00027	00010	-00004	00000	00000		
N02	-00562	00655	-00122	00037	-00014	00005	00000	000 0		
N03	00098	-00122	00042	-00028	00015	-00005	00000	00000		
N04	-00027	00037	-00028	00038	-00040	00019	00000	00000		
N05	00010	-00014	00015	-00040	00067	-00039	00000	00000		
N06	-00004	00005	-00005	00019	-00039	00024	00000	00000		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-09087	/20008	70616	74050	49281	98689	00000	00000		

S-6-701-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000	0		.00000	-.0000	
0008.50	162¤0	078843	-002997	-0001385	-0005887	.00000	.0000	BRG
0017.00	417.5	517659	000000	-0005768	-0049024	.00000	.0000	
0040.12	417.5	517659	-048650	-0015421	-0293965	.00000	.0001	
0063.24	162¤0	078843	000000	-0073725	-1886882	-.00000	.0001	
0071.74	162¤0	078843	106031	-0075110	-2519427	-.00003	.0000	BRG
0080.24	122.2	044304	000000	0029536	-2262483	-.00005	-.0003	
0298.74	122.2	044304	000000	0002846	1275307	-.00006	-.0438	
0499.47	153.7	070135	000000	-0021673	-0614212	.00028	-.0070	
0525.74	153.7	070135	036278	-0025710	-1236588	.00025	-.0000	BRG
0552.01	133.6	070135	000000	0006530	-1012017	.00020	.0059	
0670.24	133.6	070135	000000	-0009266	-1173778	.00005	.0209	
0814.74	133.6	070135	103049	-0028572	-3907620	-.00043	-.0000	BRG
0869.94	133.6	070135	-067100	0067101	-0000082	-.00058	-.0293	
0869.95	000.0	000000	0000	-	- 82	-.00058	-.0293	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00886	-01055	00241	-00072	00000	00000				
N02	-01055	01267	-00314	00102	00000	00000				
N03	00241	-00314	00136	-00062	00000	00000				
N04	-00072	00102	-00062	00032	00000	00000				

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
— 02997	/06030	36277	/03048	00000	00000				

S-6-702-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000			.00000	-.0000	
0008.50	162¤0	078843	005676	-0001385	-0005887	.00000	.0000	BRG
0017.00	417.5	517659	000000	0002906	0024699	.00000	.0000	
0040.12	417.5	517659	-048650	-0006748	-0019716	.00000	.0001	
0063.24	162¤0	078843	000000	-0065051	-1412106	-.00000	.0001	
0071.74	162¤0	078843	093712	-0066436	-1970928	-.00002	-.0000	BRG
0080.24	122.2	044304	000000	0025891	-1744971	-.00004	-.0003	
0298.74	122.2	044304	000000	-0000799	0996282	.00002	-.0275	
0525.74	122.2	044304	058542	-0028527	-2332255	-.00006	-.0000	BRG
0752.74	122.2	044304	000000	0002286	1333905	-.00004	-.0472	
0953.47	153.7	070135	000000	-0022233	-0668007	.00029	-.0072	
0979.74	153.7	070135	037075	-0026270	-1305092	.00026	-.0000	BRG
1006.01	133.6	070135	000000	0006767	-1074285	.00021	.0061	
1124.24	133.6	070135	000000	-0009029	-1207983	.00004	.0214	
1268.74	133.6	070135	102812	-0028335	-3907526	-.00043	-.0000	BRG
1323.94	133.6	070135	-067100	0067102	0000029	-.00059	-.0296	
1323.95	000.0	000000	0 0		29	-.00059	-.0296	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00838	-00987	00193	-00063	00019	00000	000			
N02	-00987	01170	-00246	00089	-00027	00000	000			
N03	-00193	-00246	00099	-00078	00032	00000	000			
N04	-00063	00089	-00078	00105	-00053	00000	000			
N05	00019	-00027	00032	-00053	00029	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
05675	93712	58541	37074	/02811	00000	000	0		

S-6-703-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162□0	078843	000000			.00000	-.0000	
0008.50	162□0	078843	003396	-0001385	-0005887	.00000	.0000	BRG
0017.00	417.5	517659	000000	0000626	0005323	.00000	.0000	
0040.12	417.5	517659	-048650	-0009027	-0091791	.00000	.0001	
0063.24	162□0	078843	000000	-0067331	-1536882	-.00000	.0001	
0071.74	162□0	078843	096951	-0068716	-2115079	-.00002	-.0000	BRG
0080.24	122.2	044304	000000	0026850	-1880968	-.00004	-.0003	
0298.74	122.2	044304	000000	0000160	1069892	-.00000	-.0318	
0525.74	122.2	044304	054698	-0027568	-2040886	.00002	-.0000	BRG
0752.74	122.2	044304	000000	-0000598	0970542	.00001	-.0259	
0979.74	122.2	044304	058280	-0028326	-2312304	-.00006	-.0000	BRG
1206.74	122.2	044304	000000	0002226	1340145	-.00004	-.0476	
1407.47	153.7	070135	000000	-0022293	-0673890	.00029	-.0073	
1433.74	153.7	070135	037161	-0026331	-1312562	.00026	-.0000	BRG
1460.01	133.6	070135	000000	0006793	-1081073	.00021	.0061	
1578.24	133.6	070135	000000	-0009003	-1211706	.00004	.0215	
1722.74	133.6	070135	102786	-0028309	-3907502	-.00043	-.0000	BRG
1777.94	133.6	070135	-067100	0067102	0000057	-.00059	-.0296	
1777.95	000.0	000000	00 0		57	-.00059	-.0296	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00835	-00982	00187	-00052	00017	-00005	00000	00000		
N02	-00982	01163	-00238	00073	-00024	00007	00000	00000		
N03	00187	-00238	00089	-00059	00028	-00008	00000	00000		
N04	-00052	00073	-00059	00079	-00071	00030	00000	00000		
N05	00017	-00024	00028	-00071	00102	-00052	00000	00000		
N06	-00005	00007	-00008	00030	-00052	00029	00000	00000		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
03396	96950	54698	58280	37161	/02785	00000	00000		

S-6-801-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000	0		.00001	-.0000	
0008.50	162¤0	078843	-013930	-0001385	-0005887	.00001	.0000	BRG
0017.00	417.5	517659	000000	-0016700	-0141947	.00000	.0000	
0040.12	417.5	517659	-048650	-0026353	-0639638	.00000	.0001	
0063.24	162¤0	078843	000000	-0084657	-2485305	-.00000	.0002	
0071.74	162¤0	078843	120868	-0086042	-3210773	-.00003	.0000	BRG
0080.24	122.2	044304	000000	0033441	-2920634	-.00007	-.0004	
0331.24	122.2	044304	000000	0002782	1625388	-.00007	-.0717	
0564.47	153.7	070135	000000	-0025707	-1048066	.00037	-.0092	
0590.74	153.7	070135	042180	-0029745	-1776427	.00032	.0000	BRG
0617.01	133.6	070135	000000	0008398	-1502784	.00026	.0076	
0735.24	133.6	070135	000000	-0007398	-1443698	.00004	.0250	
0879.74	133.6	070135	101181	-0026704	-3907621	-.00047	.0000	BRG
0934.94	133.6	070135	-067100	0067101	-0000080	-.00062	-.0313	
0934.95	000.0	000000	0 0	-	- 80	-.00062	-.0313	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00782	-00914	00198	-00066	00000	00000				
N02	-00914	01076	-00251	00090	00000	00000				
N03	00198	-00251	00107	-00053	00000	00000				
N04	-00066	00090	-00053	00029	00000	00000				

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-13929	/20868	42179	/01180	00000	00000				

S-6-802-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162.0	078843	000000			.00000	-.0000	
0008.50	162.0	078843	-004204	-0001385	-0005887	.00000	.0000	BRG
0017.00	417.5	517659	000000	-0006975	-0059284	.00000	.0000	
0040.12	417.5	517659	-048650	-0016628	-0332129	.00000	.0001	
0063.24	162.0	078843	000000	-0074932	-1952951	-.00000	.0001	
0071.74	162.0	078843	107571	-0076317	-2595756	-.00003	.0000	BRG
0080.24	122.2	044304	000000	0029869	-2335980	-.00005	-.0003	
0331.24	122.2	044304	000000	-0000790	1313440	.00002	-.0478	
0590.74	122.2	044304	066423	-0032488	-3004458	-.00007	.0000	BRG
0850.24	122.2	044304	000000	0002236	1688694	-.00006	-.0764	
1083.47	153.7	070135	000000	-0026253	-1111968	.00039	-.0095	
1109.74	153.7	070135	042995	-0030290	-1854657	.00033	.0000	BRG
1136.01	133.6	070135	000000	0008668	-1573920	.00027	.0078	
1254.24	133.6	070135	000000	-0007128	-1482905	.00004	.0255	
1398.74	133.6	070135	100911	-0026434	-3907806	-.00047	.0000	BRG
1453.94	133.6	070135	-067100	0067101	-0000272	-.00062	-.0316	
1453.95	000.0	000000	0	-	- 272	-.00062	-.0316	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00735	-00849	00148	-00051	00017	00000	000			
N02	-00849	00986	-00184	00070	-00023	00000	000			
N03	00148	-00184	00067	-00057	00025	00000	000			
N04	-00051	00070	-00057	00083	-00045	00000	000			
N05	00017	-00023	00025	-00045	00027	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-04204	/07571	66422	42995	/00910	00000	000			

S-6-803-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS..	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000	0		.00000	-.0000	
0008.50	162¤0	078843	-006752	-0001385	-0005887	.00000	.0000	BRG
0017.00	417.5	517659	000000	-0009522	-0080937	.00000	.0000	
0040.12	417.5	517659	-048650.	-0019175	-0412679	.00000	.0001	
0063.24	162¤0	078843	000000	-0077479	-2092397	-.00000	.0001	
0071.74	162¤0	078843	111056	-0078864	-2756855	-.00003	-.0000	BRG
0080.24	122.2	044304	000000	0030807	-2489110	-.00006	-.0004	
0331.24	122.2	044304	000000	0000147	1395623	-.00000	-.0540	
0590.74	122.2	044304	062667	-0031551	-2678995	.00002	-.0000	BRG
0850.24	122.2	044304	000000	-0000582	1282912	.00001	-.0454	
1109.74	122.2	044304	066151	-0032279	-2980803	-.00008	-.0000	BRG
1369.24	122.2	044304	000000	0002173	1695963	-.00006	-.0770	
1602.47	153.7	070135	000000	-0026316	-1119426	.00039	-.0095	
1628.74	153.7	070135	043091	-0030353	-1863774	.00033	-.0000	BRG
1655.01	133.6	070135	000000	0008700	-1582195	.00027	.0078	
1773.24	133.6	070135	000000	-0007096	-1487392	.00004	.0256	
1917.74	133.6	070135	100879	-0026402	-3907663	-.00047	-.0000	BRG
1972.94	133.6	070135	-067100	0067101	-0000114	-.00062	-.0317	
1972.95	000.0	000000	0		- 114	-.00062	-.0317	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00731	-00844	00144	-00040	00014	-00005	00000	00000		
N02	-00844	00980	-00177	00054	-00019	00006	00000	00000		
N03	00144	-00177	00060	-00040	00020	-00007	00000	00000		
N04	-00040	00054	-00040	00053	-00052	00024	00000	00000		
N05	00014	-00019	00020	-00052	00082	-00045	00000	00000		
N06	-00005	00006	-00007	00024	-00045	00026	00000	00000		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-06751	/11055	62667	66150	43090	/00878	00000	00000		

S-6-901-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162¤0	078843	000000			.00001	-.0001	
0008.50	162¤0	078843	-026263	-0001385	-0005887	.00001	.0000	BRG
0017.00	417.5	517659	000000	-0029033	-0246783	.00001	.0001	
0040.12	417.5	517659	-048650	-0038687	-1029629	.00000	.0002	
0063.24	162¤0	078843	000000	-0096990	-3160450	-.00001	.0002	
0071.74	162¤0	078843	137134	-0098375	-3990754	-.00004	-.0000	BRG
0080.24	122.2	044304	000000	0037374	-3667190	-.00009	-.0005	
0363.74	122.2	044304	000000	0002744	2019545	-.00009	-.1111	
0629.47	153.7	070135	000000	-0029715	-1563884	.00048	-.0117	
0655.74	153.7	070135	048336	-0033752	-2397521	.00041	-.0000	BRG
0682.01	133.6	070135	000000	0010547	-2067422	.00032	.0095	
0800.24	133.6	070135	000000	-0005249	-1754250	.00003	.0296	
0944.74	133.6	070135	099032	-0024555	-3907631	-.00051	-.0000	BRG
0999.94	133.6	070135	-067100	0067101	-0000092	-.00066	-.0337	
0999.95	000.0	000000	0 0	-	- 92	-.00066	-.0337	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00701	-00807	00166	-00060	00000	0000				
N02	-00807	00934	-00207	00080	00000	0000				
N03	00166	-00207	00088	-00047	00000	00000				
N04	-00060	00080	-00047	00027	00000	00000				

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-26263	37134	48336	99031	00000	00000				

S-6-902-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162□0	078843	000000	0		.00001	-.0001	
0008.50	162□0	078843	-015439	-0001385	-0005887	.00001	.0000	BRG
0017.00	417.5	517659	000000	-0018209	-0154780	.00001	.0000	
0040.12	417.5	517659	-048650	-0027863	-0687375	.00000	.0002	
0063.24	162□0	078843	000000	-0086166	-2567947	-.00000	.0002	
0071.74	162□0	078843	122780	-0087551	-3306247	-.00004	.0000	BRG
0080.24	122.2	044304	000000	0033844	-3012691	-.00007	-.0004	
0363.74	122.2	044304	000000	-0000786	1673211	.00003	-.0775	
0655.74	122.2	044304	074328	-0036454	-3763815	-.00009	-.0000	BRG
0947.74	122.2	044304	000000	0002207	2088036	-.00007	-.1177	
1213.47	153.7	070135	000000	-0030252	-1638245	.00049	-.0120	
1239.74	153.7	070135	049180	-0034290	-2486004	.00042	-.0000	BRG
1266.01	133.6	070135	000000	0010853	-2147876	.00033	.0098	
1384.24	133.6	070135	000000	-0004944	-1798568	.00002	.0302	
1528.74	133.6	070135	098726	-0024250	-3907785	-.00052	-.0000	BRG
1583.94	133.6	070135	-067100	0067101	-0000248	-.00067	-.0340	
1583.95	000.0	000000	0 0	-	- 248	-.00067	-.0340	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00654	-00744	00118	-00043	00016	00000	000			
N02	-00744	00851	-00143	00057	-00021	00000	000			
N03	00118	-00143	00048	-00043	00021	00000	000			
N04	-00043	00057	-00043	00069	-00040	00000	000			
N05	00016	-00021	00021	-00040	00024	00000	000			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-15439	/22780	74328	49179	98725	00000	000	0		

S-6-903-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	162.0	078843	000000	0		.00001	-.0001	
0008.50	162.0	078843	-018269	-0001385	-0005887	.00001	.0000	BRG
0017.00	417.5	517659	000000	-0021039	-0178833	.00001	.0001	
0040.12	417.5	517659	-048650	-0030693	-0776854	.00000	.0002	
0063.24	162.0	078843	000000	-0088996	-2722852	-.00000	.0002	
0071.74	162.0	078843	126535	-0090381	-3485206	-.00004	-.0000	BRG
0080.24	122.2	044304	000000	0034768	-3183789	-.00007	-.0005	
0363.74	122.2	044304	000000	0000139	1764287	-.00000	-.0863	
0655.74	122.2	044304	070625	-0035529	-3402702	.00003	-.0000	BRG
0947.74	122.2	044304	000000	-0000571	1637932	.00002	-.0741	
1239.74	122.2	044304	074048	-0036239	-3736444	-.00010	-.0000	BRG
1531.74	122.2	044304	000000	0002141	2096317	-.00007	-.1185	
1797.47	153.7	070135	000000	-0030318	-1647337	.00050	-.0121	
1823.74	153.7	070135	049282	-0034355	-2496813	.00042	-.0000	BRG
1850.01	133.6	070135	000000	0010889	-2157716	.00033	.0098	
1968.24	133.6	070135	000000	-0004907	-1804047	.00002	.0303	
2112.74	133.6	070135	098689	-0024213	-3907933	-.00052	-.0000	BRG
2167.94	133.6	070135	-067100	0067101	-0000419	-.00067	-.0341	
2167.95	000.0	000000	00 0	- 1	-0000419	-.00067	-.0341	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00651	-00740	00114	-00031	00012	-00004	00000	00000		
N02	-00740	00845	-00137	00042	-00015	00006	00000	00000		
N03	00114	-00137	00042	-00028	00015	-00005	00000	00000		
N04	-00031	00042	-00028	00038	-00040	00019	00000	00000		
N05	00012	-00015	00015	-00040	00067	-00039	00000	00000		
N06	-00004	00006	-00005	00019	-00039	00024	00000	00000		

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-18269	26534	70625	74048	49281	98688	00000	00000		

S-9-801

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	186.0	102727	000000	000		.00001	-.0001	
0014.35	186.0	102727	-008421	-0002669	-0019151	.00001	.0000	BRG
0028.70	461.0	631158	000000	-0013759	-0197446	.00001	.0001	
0052.85	461.0	631158	-053540	-0024894	-0664178	.00001	.0003	
0077.00	186.0	102727	000000	-0089568	-2692793	-.00000	.0003	
0091.35	186.0	102727	133827	-0092237	-3997241	-.00005	-.0000	BRG
0105.70	138.4	056883	000000	0038921	-3419571	-.00010	-.0011	
0363.35	138.4	056883	000000	0003260	2014445	-.00007	-.0759	
0607.25	175.8	091816	000000	-0030498	-1307195	.00037	-.0098	
0635.35	175.8	091816	050336	-0035439	-2233610	.00032	-.0000	BRG
0663.45	152.9	091816	000000	0009955	-1884442	.00026	.0081	
0786.35	152.9	091816	000000	-0008832	-1815436	.00004	.0261	
0937.35	152.9	091816	119336	-0031915	-4891889	-.00047	-.0000	BRG
0996.35	152.9	091816	-078400	0078401	-0000138	-.00062	-.0337	
0996.36	000.0	000000	0 0	-	- 138	-.00062	-.0337	

S-9-801

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00648	-00775	00191	-00064	00000	00000	0			
N02	-00775	00936	-00252	00091	00000	00000	0			
N03	00191	-00252	00121	-00060	00000	00000				
N04	-00064	00091	-00060	00033	00000	00000				

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-08421	133827	50335	119336	00000	00000	-			

S-9-801-A

SHAFT LOC. IN.	WEIGHT LBS/IN.	EI	CONC. LD. LBS.	SHEAR LBS.	MOMENT INCH LBS.	SLOPE RADIANS	DEFLECT. INCHES	
0000.00	186.0	102727	000000	00		.00001	-.0001	
0014.35	186.0	102727	-005300	-0002669	-0019151	.00001	.0000	BRG
0028.70	461.0	631158	000000	-0010638	-0152662	.00001	.0001	
0052.85	461.0	631158	-053540	-0021773	-0544028	.00000	.0002	
0077.00	186.0	102727	000000	-0086447	-2497276	-.00000	.0003	
0091.35	186.0	102727	129370	-0089116	-3756940	-.00004	.0000	BRG
0105.70	138.4	056883	000000	0037585	-3198450	-.00009	-.0010	
0363.35	138.4	056883	000000	0001924	1891188	-.00004	-.0679	
0607.25	175.8	091816	000000	-0031834	-1756451	.00028	-.0070	
0635.35	175.8	091816	063052	-0036776	-2720424	.00021	-.0000	BRG
0663.45	152.9	091816	000000	0021335	-2051473	.00014	.0049	
0786.35	152.9	091816	000000	0002548	-0583837	-.00001	.0109	
0937.35	152.9	091816	057956	-0020535	-1941874	-.00017	-.0000	BRG
0996.35	152.9	091816	-028400	0028401	-0000124	-.00023	-.0124	
0996.36	000.0	000000	0	-	- 124	-.00023	-.0124	

BEARING REACTION INFLUENCE NUMBERS LBS. PER .001 INCH RISE OF BEARING

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
N01	00648	-00775	00191	-00064	00000	00000	0			
N02	-00775	00936	-00252	00091	00000	00000	0			
N03	00191	-00252	00121	-00060	00000	00000				
N04	-00064	00091	-00060	00033	00000	00000	0			

STRAIGHT LINE REACTION LBS

R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
-05300	129369	63052	57955	00000	00000	0			

APPENDIX "G"

COMPUTER PROGRAM DESCRIPTION

APPENDIX "G"

DESCRIPTION OF COMPUTER PROGRAM *

*METHOD OF CALCULATION

"Although the texts on indeterminate structures illustrate various devices for handling continuous beams on multiple supports, such as Hardy Cross, or Relaxation Method, Three Moment Equations, etc., the large memory capacity and speed of a digital computer permits a more "classical" approach. This approach is based on a direct evaluation of the relationship of the beam load (w) to the deflection (y).

$$EI \frac{d^4y}{dx^4} = w$$

"Therefore, successive integrations of the load-stiffness diagram will yield shear, moment, slope and deflection. However, in order to obtain zero deflection at each support, the correct reactions would have to be included in the load diagram prior to the integration. In the shafting problem, the reactions at each support are the unknowns.

"If the reactions are not included in the load diagram and it is assumed that the beam is held firmly at one end, the successive integrations will result in a deflection diagram similar to that shown in Figure 1 (a). Applying estimated reactions whose magnitudes are proportional to the deflection will yield a diagram with a smaller deflection, as shown in Figure 1 (b). Further approximations and successive integrations will converge to a zero deflection at the supports, as shown in Figure 1 (c). At this point, the correct reaction has been applied.

"In order to apply this principle to practical use, some method of obtaining reaction estimates had to be devised. The method used is to determine the amount of reaction change produced by raising or lowering a bearing support a unit amount. This is also one of the final answers to our problem. These "influence numbers" are obtained by assuming the shaft has no weight and that a unit reaction is applied to one bearing. Successive integrations will then yield resulting deflections at all other bearing locations. By applying this unit reaction to each support in turn, a family of deflections will be obtained which can be substituted into a set of equations (two more equations than there are number of support points), expressing the relationship of reactions and deflections. Solution of these equations will yield the "influence numbers" necessary to the final solution of straight line reactions.

"Multiplying the influence numbers by the deflections obtained from integration of the unsupported, weighted (real) shaft, and summing the reaction changes for each bearing, the final straight line reactions will result. Applying this total reaction for each bearing to the load diagram and repeating the integration process, the deflection at each support will be zero, thus proving that the correct reaction has been applied. If the deflection is not zero, the entire process can be repeated until the bearing deflection becomes trivial."

A more detailed discussion of the approach used to solve this problem will be found in the section "Theory."

---

* "Calculation of Ship Propulsion Shafting Bearing Reactions for an IBM-650 Computer", Developement Report No. R-11, 1 October, 1957, by Edward T. Antkowiak, Boston Naval Shipyard, as revised by G.E. Co.

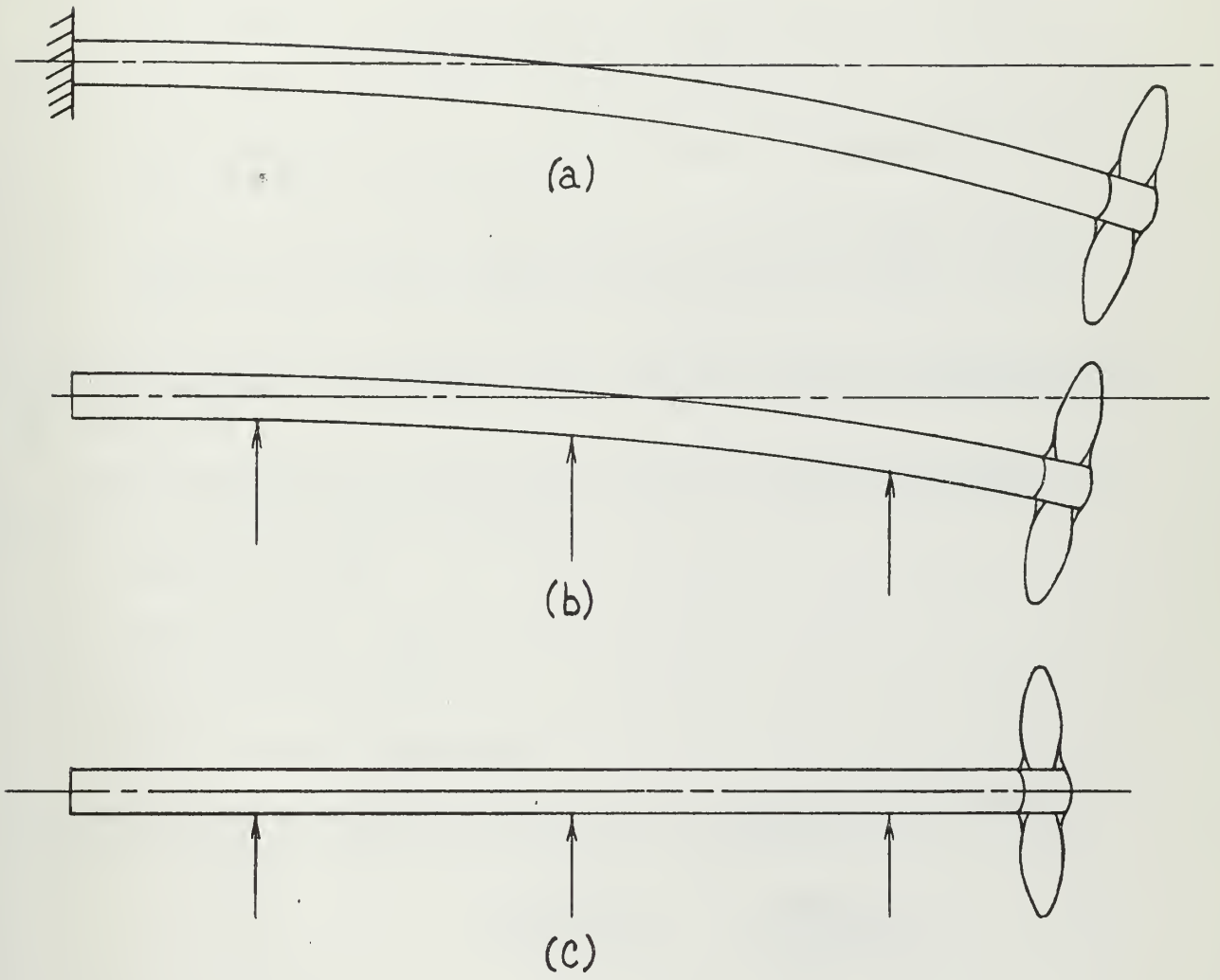


Figure 1 - CONVERGENCE OF SHAFT DEFLECTION CURVE TO A STRAIGHT LINE BY ADDING SUPPORTING REACTIONS

PROGRAM DESCRIPTION

In order to accomplish the objectives outlined in "Method of Calculation" the shafting system must be divided into a number of uniform stations. The number of stations is left to the discretion of the user, subject to the following restrictions:

1. Total number of stations must not exceed 99.

2. Total number of supports must not exceed 22.

3. Each change in diameter, bearing location, and concentrated load, must initiate a new station.

4. Lengths of stations are arbitrary, but the user should provide sufficient stations to obtain points for plotting shear, moment, slope and deflection diagrams, if desired.

The preparation of the input data is more thoroughly covered in the section "Input Data" and Figure 7 shows a shaft sectioned for preparation of the input data.

The program has been written in as general a manner as possible, and provides for the following variables:

1. Material of shaft

2. Shaft in water or air

3. Shaft solid or hollow

4. Sand in bore of hollow shaft

The program is presently written using certain specific moduli and densities of steel, bronze, sand, and water, as follows:

	Density (Lbs/Cu.In.)	Modulus (Lbs/Sq.In.)
Steel	-.28355	30×10^6
Bronze	-.31399	15×10^6
Sand	-.0636	
Water	-.03705	

If materials used in a specified shaft have constants which are quite different than those given above, it is possible to add additional values as desired. This feature is covered in more detail in "Input Data."

The program gives the magnitude of all bearing reactions, assuming all bearings are on a straight line, and furnishes a table of influence numbers which are the amount of change in all bearing loads resulting from raising a particular bearing .001" from the straight line. Values of shear, moment,

slope and deflection are given for each station, with all bearings on a straight line, and also weight (in lb/in.) at each station, and the stiffness (in terms of $\frac{1}{EI}$). The total weight of the shaft and the location of the center of gravity is also printed. A more complete description of the output is included in the section "Output Data."

THEORY

The following description by Mr. Sibley gives in more detail the theoretical approach to this calculation. Mr. Ralph E. Wolfe of the Scientific Section, Boston Naval Shipyard, contributed greatly to this approach and originated the concept of obtaining the influence numbers, described herein by integration of a "weightless" shaft.

1. The input (from cards) specifies:-

   Length to one end----------x

   Outer diameter----------d_a

   Second diameter----------d_b

   Third diameter----------d_c

   Concentrated Weight--------W

   First Material----------a

   Second Material----------b

   Presence of bearings, immersion in water, presence of sand in bore.

   See Fig. 2

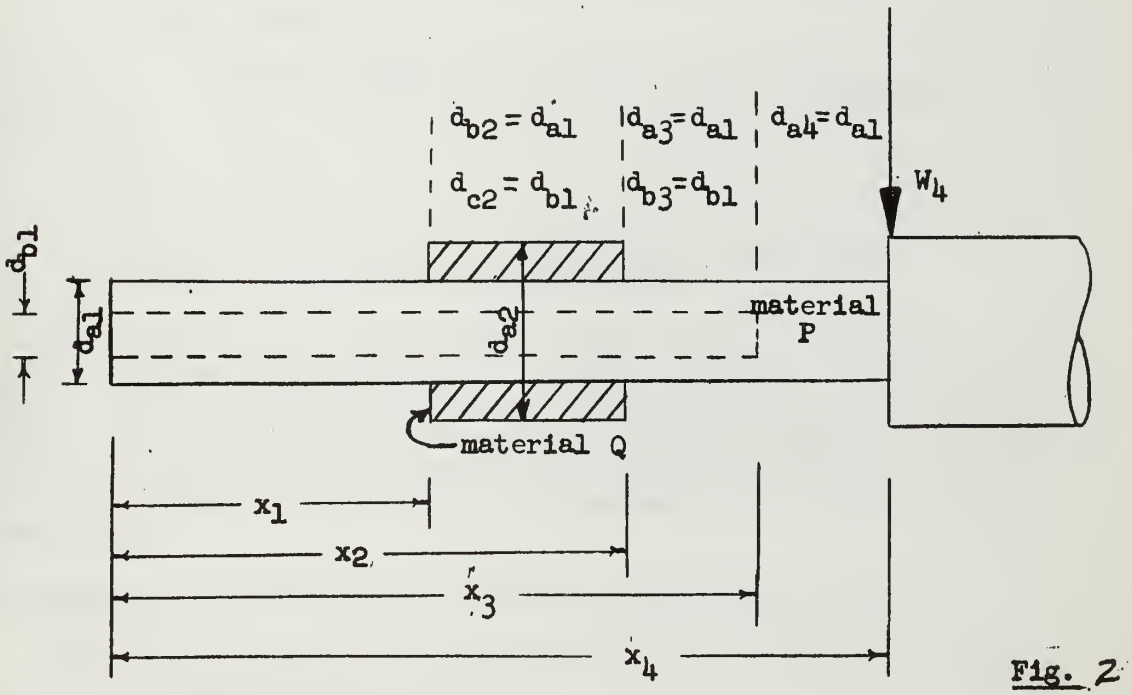


Fig. 2

$a_1 = P$
$a_2 = Q$, $b_2 = P$
$a_3 = P$

2. The first part of the program finds the moment of inertia and weight per unit length as follows:-

$$\text{Outer Area} = \frac{\pi}{4}(d_a^2 - d_b^2) = A_a$$

$$\text{Inner Area} = \frac{\pi}{4}(d_b^2 - d_c^2) = A_b$$

$$\text{Innermost Area} = \frac{\pi}{4} d_c^2 = A_c$$

$$\text{Inertia of outer part} = \frac{\pi}{64}(d_a^4 - d_b^4) = I_a$$

$$\text{Inertia of inner part} = \frac{\pi}{64}(d_b^4 - d_c^4) = I_b$$

If the density of material a is ρ_a; material b is ρ_b, etc., then:

$$\text{Weight per unit length} = A_a\rho_a + A_b\rho_b + A_c\rho_c - (A_a + A_b + A_c)\rho_d$$

The first term (a) must be present in all cases; the second term (b) will be present for two materials; the third (c) is only present if the bore is filled with sand; and the fourth term (d), which represents the upthrust of the water, is only present if the shaft is partly or wholly immersed in water.

If the modulus of elasticity (Young's Modulus) of material a is designated E_a, the stiffness of a two material section will be;

$$S_T = E_a I_a + E_b I_b$$

The section length is found by subtracting the end lengths of adjacent sections:

$$l_n = X_n - X_{n-1}$$

3. A ficticious shaft is now considered, of no weight, but each section having the same stiffness as the real shaft.

If this were put into the bearings, there will be no reaction if the bearings are in an exact straight line. However, if one of the bearings is raised by one mil, the others remaining on the line, forces will appear at each bearing. These forces are known as the "INFLUENCE NUMBERS" which form an n x n matrix, where n is the number of bearings; the element in the p column and q row giving the force on bearing number p for a deflection of 1 mil at bearing q.

The method of calculating the influence numbers as follows:

Consider the weightless shaft acting as a cantilever as shown in fig. 3 with a unit force applied at B.

If such a force is applied, section AB will be straight, but inclined at an angle to the horizontal. As will be seen later, there is an advantage to assuming that the section AB remains horizontal, and the wall is moved.

This is merely a matter of using AB as the reference axis.

Now consider the shear force, bending moment, slope and deflection diagrams. It is appreciated, from theory of beam deflection, that these diagrams are related to one another by integration.

If W is the weight, S the shear, M the moment, θ the slope and δ the deflection, the integrals are shown in figure 4, and are:

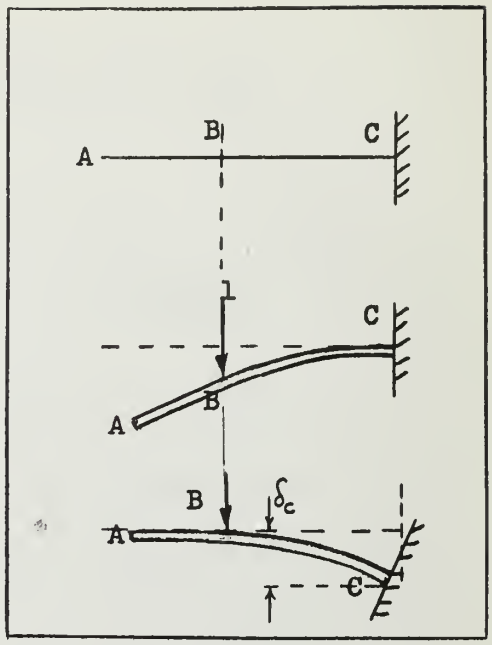


Fig. 3

$$S_L = \int_0^L W \, dl$$

$$M_L = \int_0^L S \, dl$$

$$\theta_L = \frac{1}{E\,I} \int_0^L M \, dl$$

$$\delta_L = \int_0^L \theta_L \, dl$$

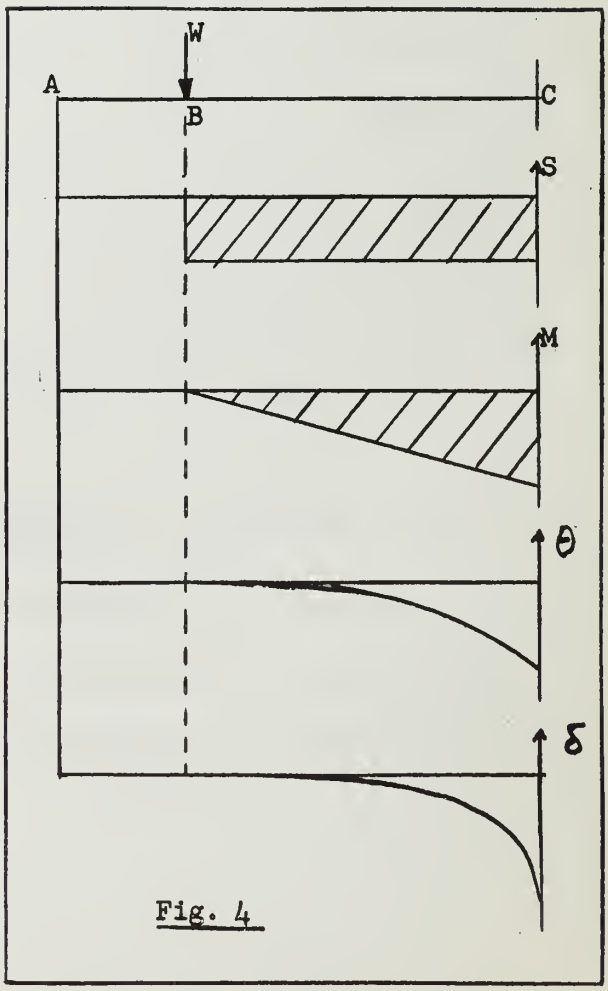


Fig. 4

The result of a series of such integrations can be summarized in the following tabular (or matrix) form:

Force applied at station No:							Deflection at station number					
1	2	3	4	5	6		1	2	3	4	5	6
1							0	d_{12}	d_{13}	d_{14}	d_{15}	d_{16}
	1						0	0	d_{23}	d_{24}	d_{25}	d_{26}
		1					0	0	0	d_{34}	d_{35}	d_{36}
			1				0	0	0	0	d_{45}	d_{46}
				1			0	0	0	0	0	d_{56}
					1		0	0	0	0	0	0

Thus d_{24} is the deflection at station 4 for a force of unity applied at station 2.

Now if the beam end A is <u>not</u> horizontal or at zero slope, these deflections must be ammended as follows:

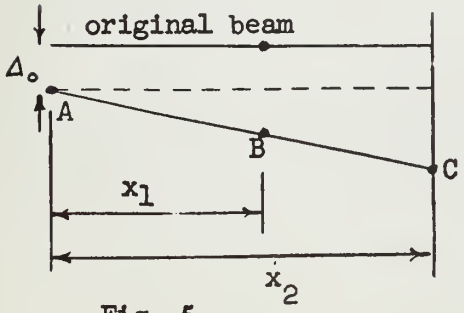


Fig. 5

To deflection at A----add Δ_o

To deflection at B----add $\Delta_o + \theta_o x_1$

To deflection at C----add $\Delta_o + \theta_o x_2$

See Fig. 5

Now suppose that instead of a unit reaction at a single support, there are reactions R_1, R_2 etc. at 1, 2 respectively.

Then the following equations apply:

Deflection at B = $\delta_1 = \Delta_0 + \theta_0 x_1$

$$\delta_2 = \Delta_0 + \theta_0 x_2 + d_{12} R_1$$

$$\delta_3 = \Delta_0 + \theta_0 x_3 + d_{13} R_1 + d_{23} R_2$$

etc.

Two further equations are required to solve this set, and these are found from the conditions at the end (shown as C in figure 5) which was considered as fixed. When acting as a mulitply supported beam, this free end cannot have either shear or moment. Thus:

$$0 = R_1 + R_2 + R_3 + \cdots + R_n$$

$$0 = x_1 R_1 + x_2 R_2 + \cdots + x_n R_n$$

All these equations can therefore be put into the matrix form:

$$\begin{bmatrix} \delta_1 \\ \delta_2 \\ \cdot \\ \cdot \\ \cdot \\ \delta_n \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & \cdot & \cdot & \cdot \\ 1 & 1 & d_{12} & 0 & 0 & \cdot & \cdot & \cdot \\ \cdot & \cdot & d_{13} & d_{23} & 0 & \cdot & \cdot & \cdot \\ \cdot & \cdot & d_{14} & d_{24} & d_{34} & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 1 & 1 & d_{1n} & d_{2n} & d_{3n} & \cdot & \cdot & \cdot \\ 0 & 0 & 1 & 1 & 1 & \cdot & \cdot & \cdot \\ 0 & 0 & x_1 & x_2 & x_3 & \cdot & \cdot & \cdot \end{bmatrix} \times \begin{bmatrix} \Delta_0 \\ \theta_0 \\ R_1 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ R_n \end{bmatrix}$$

In this equation, the square matrix represents the deflections for a given reaction. Inversion of this matrix will therefore give the reactions for a given deflection; or the INFLUENCE numbers. The first two columns, which gave the deflection and slope condition, now give the slope and deflection influence numbers (i.e. the end slope and deflection for a given deflection at an intermediate point).

For example, if the inverted matrix has an element α_{32} in the second column, third row this represents the reaction at support 3 for a theoretical deflection of 1 inch at bearing 2 (this number is scaled in the program for 0.001").

This means that assuming no external forces or weight:

$$R_3 = \delta_1 \alpha_{31} + \delta_2 \alpha_{32} + \delta_3 \alpha_{33} + \cdots$$

and $$\theta_0 = \delta_1 \alpha_{21} + \delta_2 \alpha_{22} + \delta_3 \alpha_{23} + \cdots$$

4. Consider the actual shaft, with only the two external bearings present, but held at the end to ensure no slope and deflection initially. If the total shaft weight is W, and the total moment from the other end is M, with a total length L (See Fig. 6)

Then: $R_a + R_b = -W$

and $(L-x_1)R_a + (L-x_n)R_b = -M$

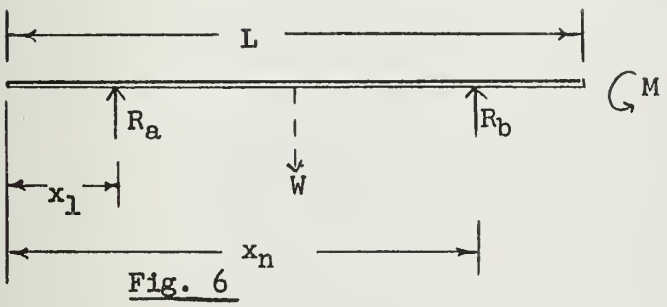


Fig. 6

(The convention assumed is that all downward forces are negative.)

From these equations, R_a and R_b are found. Now considering the real, weighted shaft, with concentrated loads, the new moments, slopes and deflections can be found.

This gives the solution to the two bearing problem. Now the other bearings are effectively absent, or can be considered as off-line, with zero reaction. Thus by using the INFLUENCE numbers, the effect of raising or lowering all the bearings to their correct position can be found. The actual answers from the inversion will not be perfectly exact, but by reentry into the deflection integration routines, corrected values of the deflection at all bearings will be found. Repeating the procedure results in the correct results.

The Computer will probably only require to make two passes through the integration routine to obtain results within the required margin.

The results should give zero deflection at a bearing and no shear force or moment at the free end: the machine checks to make sure that:

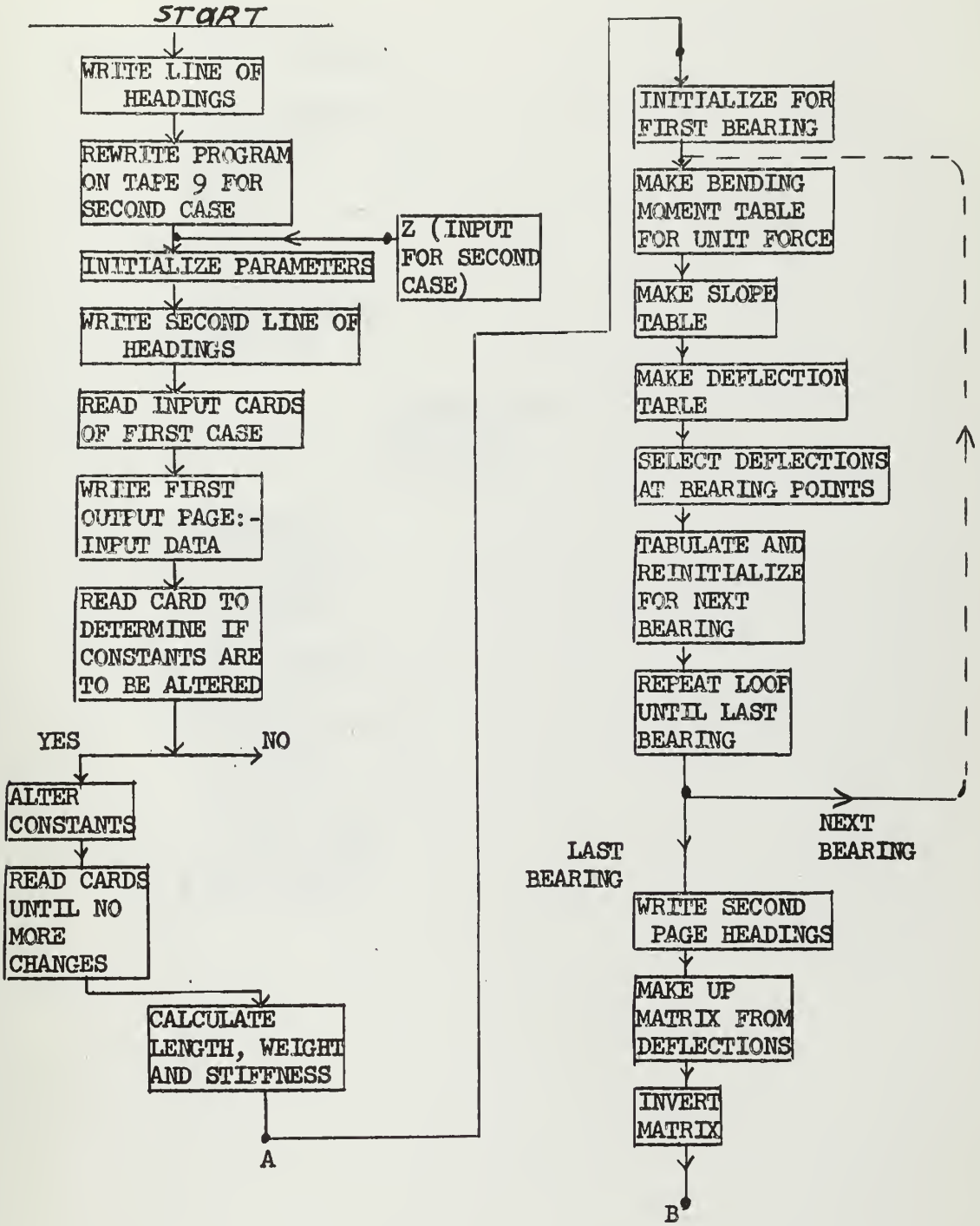
(a) No deflection at a bearing greater than 0.001"

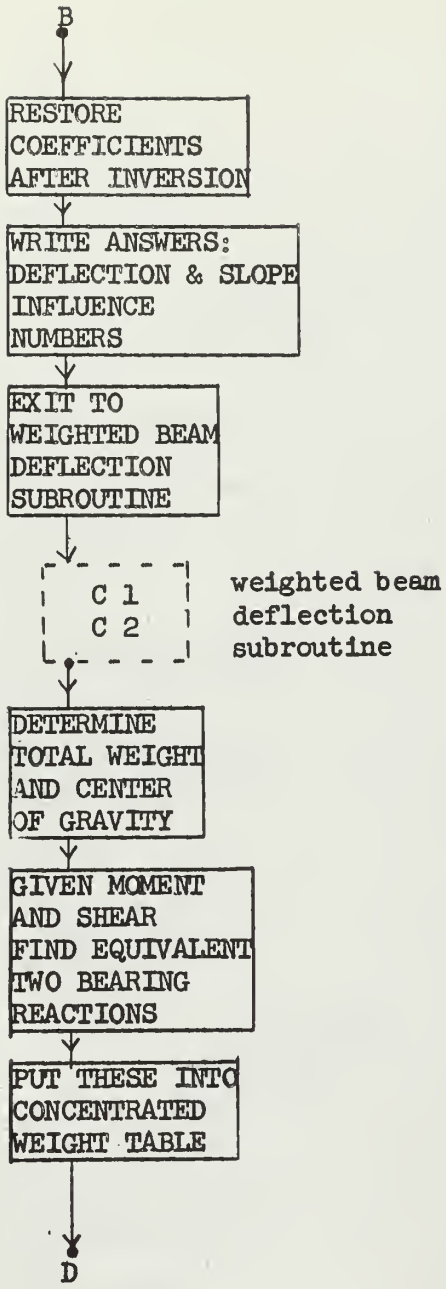
(b) Shear force at free end less than 10 lb.

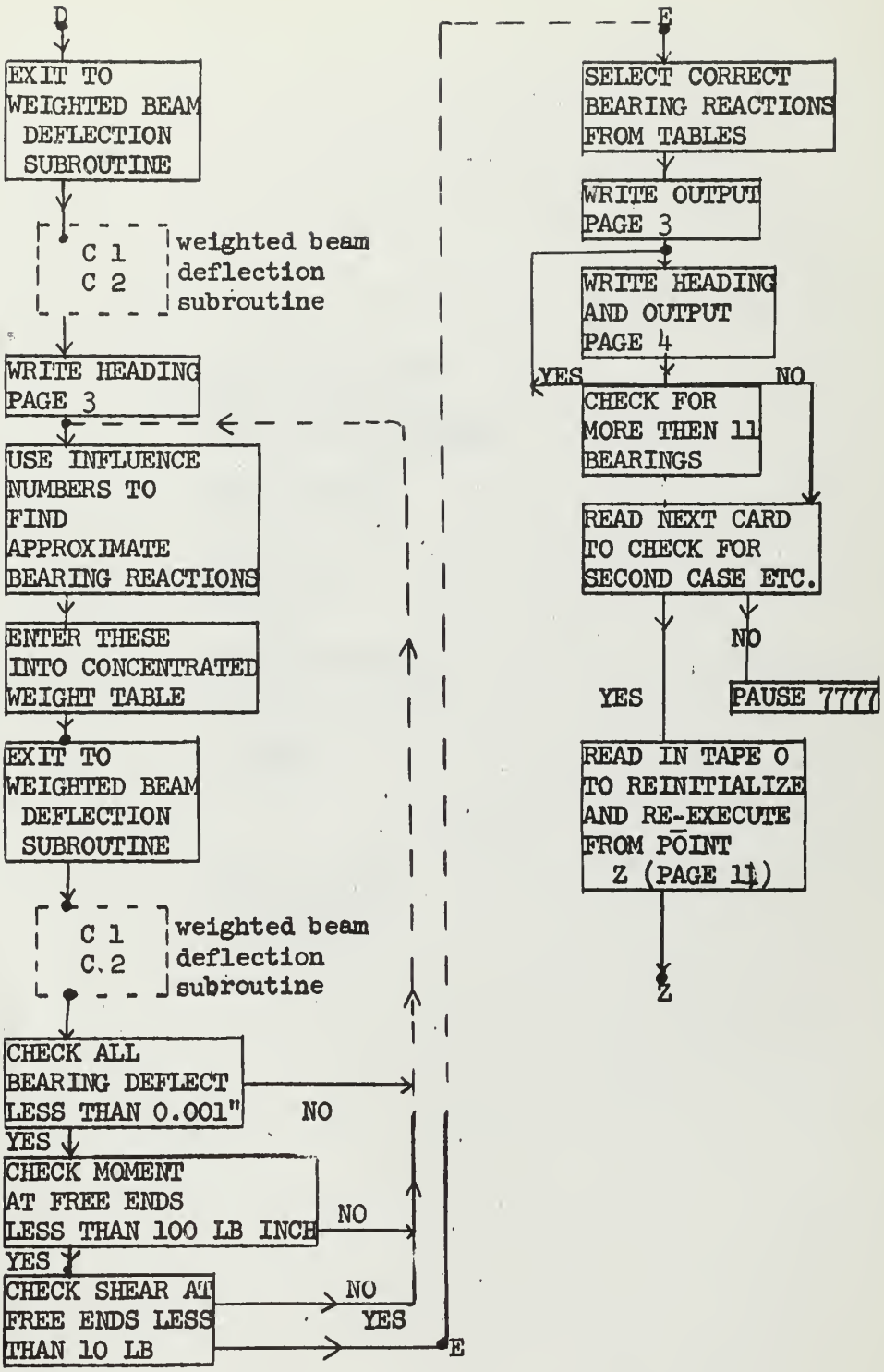
(c) Bending moment at free end less than 100 inch lb.

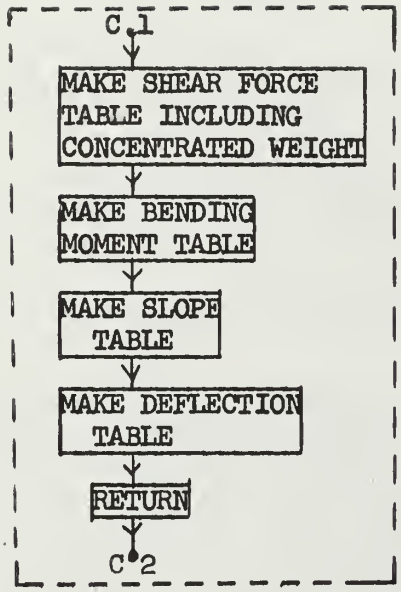
FLOW CHART

The following is a graphical representation of the operations of this program:


START
WRITE LINE OF HEADINGS
REWRITE PROGRAM ON TAPE 9 FOR SECOND CASE
Z (INPUT FOR SECOND CASE)
INITIALIZE PARAMETERS
WRITE SECOND LINE OF HEADINGS
READ INPUT CARDS OF FIRST CASE
WRITE FIRST OUTPUT PAGE:- INPUT DATA
READ CARD TO DETERMINE IF CONSTANTS ARE TO BE ALTERED
YES
NO
ALTER CONSTANTS
READ CARDS UNTIL NO MORE CHANGES
CALCULATE LENGTH, WEIGHT AND STIFFNESS
A
INITIALIZE FOR FIRST BEARING
MAKE BENDING MOMENT TABLE FOR UNIT FORCE
MAKE SLOPE TABLE
MAKE DEFLECTION TABLE
SELECT DEFLECTIONS AT BEARING POINTS
TABULATE AND REINITIALIZE FOR NEXT BEARING
REPEAT LOOP UNTIL LAST BEARING
NEXT BEARING
LAST BEARING
WRITE SECOND PAGE HEADINGS
MAKE UP MATRIX FROM DEFLECTIONS
INVERT MATRIX
B


B
RESTORE COEFFICIENTS AFTER INVERSION
WRITE ANSWERS: DEFLECTION & SLOPE INFLUENCE NUMBERS
EXIT TO WEIGHTED BEAM DEFLECTION SUBROUTINE
C 1
C 2
weighted beam deflection subroutine
DETERMINE TOTAL WEIGHT AND CENTER OF GRAVITY
GIVEN MOMENT AND SHEAR FIND EQUIVALENT TWO BEARING REACTIONS
PUT THESE INTO CONCENTRATED WEIGHT TABLE
D


D
EXIT TO WEIGHTED BEAM DEFLECTION SUBROUTINE
C 1
C 2
weighted beam deflection subroutine
WRITE HEADING PAGE 3
USE INFLUENCE NUMBERS TO FIND APPROXIMATE BEARING REACTIONS
ENTER THESE INTO CONCENTRATED WEIGHT TABLE
EXIT TO WEIGHTED BEAM DEFLECTION SUBROUTINE
C 1
C 2
weighted beam deflection subroutine
CHECK ALL BEARING DEFLECT LESS THAN 0.001"
NO
YES
CHECK MOMENT AT FREE ENDS LESS THAN 100 LB INCH
NO
YES
CHECK SHEAR AT FREE ENDS LESS THAN 10 LB
NO
YES
E
E
SELECT CORRECT BEARING REACTIONS FROM TABLES
WRITE OUTPUT PAGE 3
WRITE HEADING AND OUTPUT PAGE 4
YES
NO
CHECK FOR MORE THEN 11 BEARINGS
READ NEXT CARD TO CHECK FOR SECOND CASE ETC.
NO
YES
PAUSE 7777
READ IN TAPE 0 TO REINITIALIZE AND RE-EXECUTE FROM POINT Z (PAGE 11)
Z



WEIGHTED BEAM
DEFLECTION
SUBROUTINE

PREPARATION OF INPUT DATA

SKETCH OF LINE SHAFT ARRANGEMENT

Figure 7 is a sketch of a typical line shaft, dimensioned for preparation of input data. A sketch such as this should be prepared and checked for accuracy before the input cards are punched. The following is our recommended procedure for preparation of this sketch:

1. Obtain necessary reference drawings:

   (a) Low speed Gear and Shaft Assembly
   (b) Low speed Shaft
   (c) L.S. Gear Fabricating Assembly
   (d) Line Shaft Arrangement (from Shipyard)
   (e) Line Shaft Details (from Shipyard)

2. We suggest making the sketch to some appropriate scale, so relationship of components can be readily observed. (The gear is not necessarily made to the same scale as the remainder of the line shaft.)

3. The total number of stations must not exceed 99; and the total number of support points must not exceed 22.

4. Station 1 is the forward end of the shaft, from which the beginning of each station is dimensioned. As mentioned before, any number of stations may be used, (providing it does not exceed 99,); however, a station must be initiated at each support point, concentrated load, and significant change in diameter. In order to reduce the number of stations, slight changes in diameters may be ignored or combined, when their effect on the weight and stiffness of the shaft is insignificant. Note in Figure 7, since the journal sections were only 1/4" greater than the shaft, they were considered as being the same diameter as the shaft. Also, in this case, the average diameter of the tapered propeller section was used. *

5. In those cases where the thrust collar is forward of the L. S. gear and not integral, its weight is treated as a concentrated load, since it does not add significantly to the stiffness of the system. (This is illustrated in Figures 8 and 9.) In Figure 7, the thrust bearing is aft of the L. S. gear, and the thrust collar is integral with the shaft; therefore, it is treated as part of the shaft, and dimensioned as such.

6. (a) Since the gear is not a solid section, but consists of rim, webs, etc., an "equivalent" outside diameter must be used to obtain its proper lateral stiffness. Since the selection of the equivalent is not critical in influencing the final results, it is our practice to use the outside diameter of the hub section of the gear as the equivalent outside diameter.

(b) The weight of this "equivalent" gear and shaft assembly is then calculated. The difference between the total weight of the actual L. S. gear and shaft assembly and the above calculated weight of the equivalent assembly is applied as a concentrated load on this section, so that the total weight of the equivalent assembly will equal the weight of the actual assembly.

* See NOTE at end of this section.

(c) You will note in Figure 7 that this difference has been applied as one concentrated load at the centerline of the gear, mid-way between fore and aft bearings. Our present practice, however, is to divide the concentrated load by the number of webs, and apply these equal loads at the points where the webs meet the hub. Actually, it does not make any significant difference, in most cases, which method is used. To illustrate this, Figure 8 is a sketch of an equivalent L. S. gear and shaft assembly. (A different gear unit than the one in Figure 7 is used.) The total weight of the actual gear and shaft assembly, as given on its assembly drawing, is 73,900 lbs. The calculated weight of the equivalent assembly is 30,541 lbs. Therefore, the concentrated load which must be applied to the equivalent section to make it equal the weight of the actual gear and shaft, is 73,900 - 30,541= 43,609 lbs. This load was applied at the center of the gear, as shown. Output from the computer is given in the Table of Calculated Values, which shows the slope and deflection at each station and also the bearing reactions. In Figure 9, note that the concentrated load was divided and applied as four loads; and the slopes and deflections at given locations change very slightly from those in Figure 8.

7. It is assumed that all bearing reactions act at a point mid-way between the fore and aft ends of each bearing. The only exception to this is on the aft stern tubebearing, where it is assumed that the load is concentrated one shaft diameter forward of the aft end of this bearing. Actually, of course, the bearing reactions are carried on areas of the bearings, but making the assumption they act as point supports does not significantly change the calculated results. However, in the case of the relatively long stern tube bearing, there is more chance for error in making the assumption that the bearing load is concentrated one shaft diameter forward of its aft end, since actually the effective concentration point may be some distance either side of this, depending on the angle at which the stern tube was bored. It is possible, of course, to assume support points at any and several positions along the length of the bearing, if desired, for a more exact study.

8. Both the outside diameter of the bronze sleeve and the diameter of the steel shaft are given in the stern tube section, and respective materials noted.

9. Since the line shaft is usually studied waterborne, it must be noted what portion of the shaft is immersed in water, and a station initiated at the beginning of this waterborne section.

10. The weight of the propeller is applied as a concentrated load at its center of gravity. If the location of the center of gravity is not available, then it is concentrated mid-way on the tapered fit. Since the weight of the propeller is given as in air, it is compensated for the buoyancy effect in salt water by the following equation:

$$W_w = W_a \frac{543-64}{543} \quad \text{or} \quad W_w = W_a \times .88213$$

Where: 543 lb/cu.ft.= density of bronze
64 lb/cu.ft.= density of salt water
W_w= Weight of propeller in salt water
W_a= Weight of propeller in air

For the example in Figure 2: W_w= 27,600 x .88213 = 24,343 lbs.

* NOTE: As mentioned in Paragraph 4, it is our practice to ignore slight changes in diameter, such as occur at journal sections, since it would require two additional stations, and we feel it does not add significantly to the weight and stiffness of the system. However, if desired, the additional weight may be compensated for without increasing the number of stations, by adding it as a concentrated load at the centerline of the bearing. Since the program is such that concentrated loads cannot be added at the centerline of a support, these loads will not be included in the bearing reactions given as output, but must be added by hand to get the total reaction. All concentrated weights, however, are included in the total weight of the shaft.

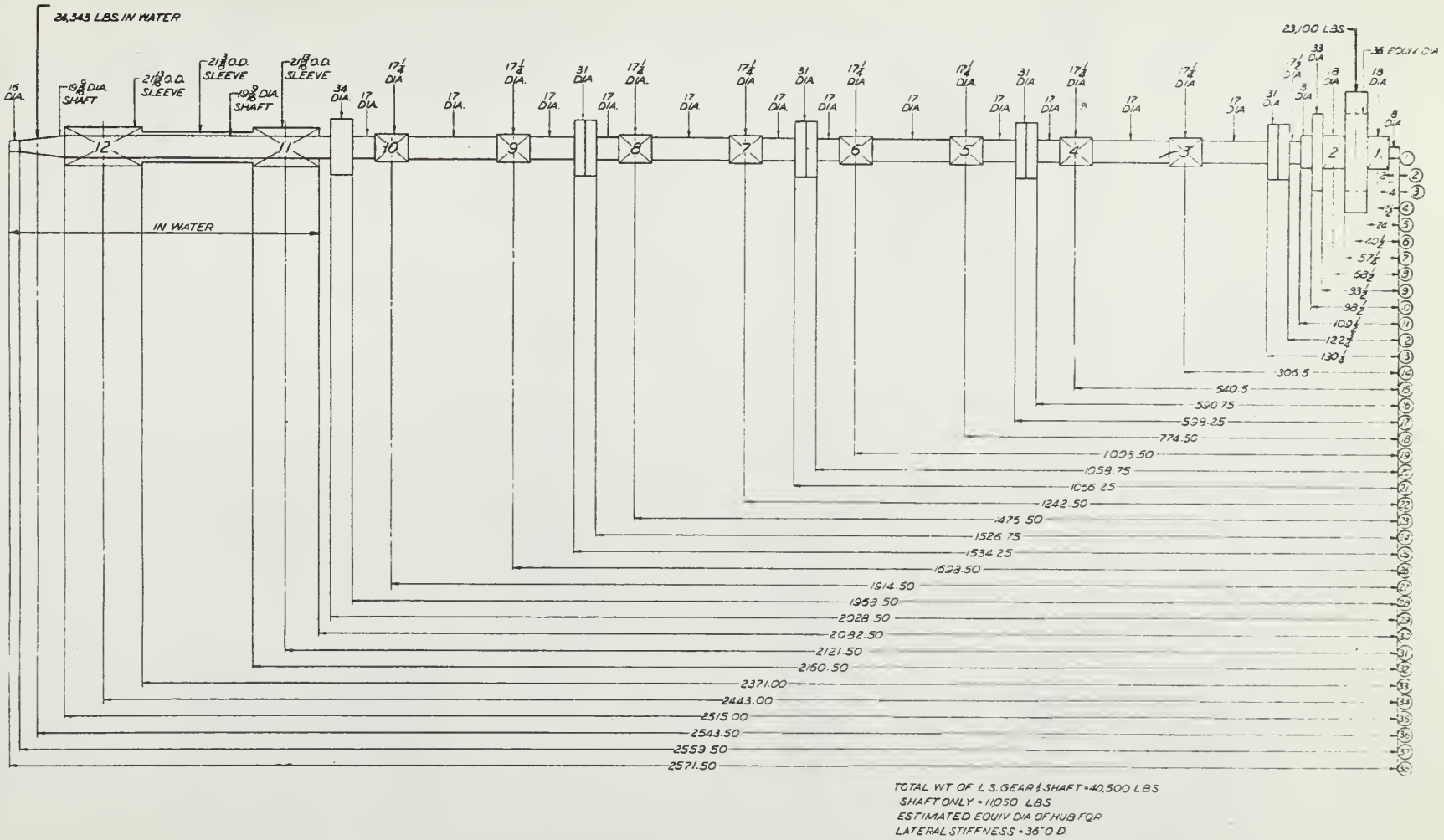


Figure 7 - SHAFTING ARRANGEMENT DIMENSIONED FOR COMPUTER PROGRAM

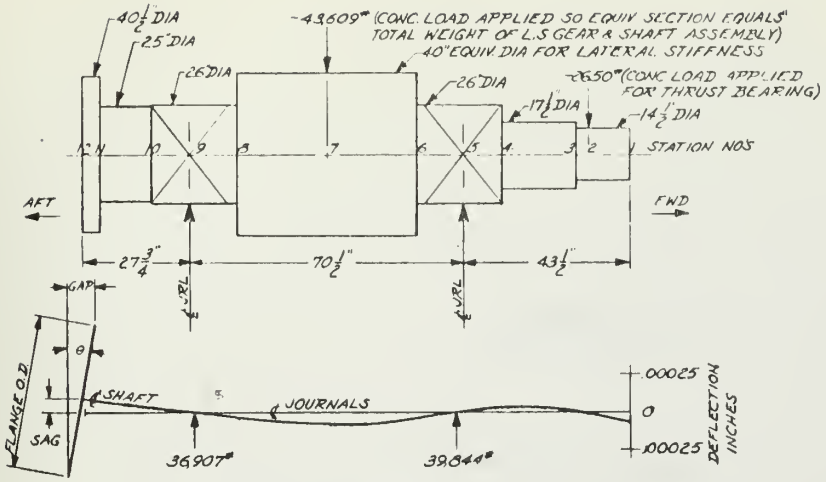


TABLE OF CALCULATED VALUES

STA NO	SLOPE (θ) (RADIANS)	DEFLECTION (INCHES)	CONC LOAD(-) OR BRG REAC.(+)
1	+.000005	-.000076	
2	+.000005	-.000022	-2650#
3	+.000004	-.000006	
4	-.000002	+.000032	
5	-.000004	0	39,844#
6	-.000003	-.000049	
7	0	-.000092	-43609#
8	+.000003	-.000059	
9	+.000005	0	36,907#
10	+.000004	+.000046	
11	+.000004	+.000092	
12	+.000004	+.000108	

AT END OF SHAFT

SAG = DEFLECTION AT STA #12 = +.00011"
GAP = (FLANGE O.D)(SIN θ)
SINCE θ = SIN θ FOR SMALL ANGLES
GAP = (FLANGE O.D)(SLOPE AT STA #12)
GAP = (40.5")(.000004) = .00016"

Figure 8 - LOW SPEED GEAR DEFLECTIONS AND BEARING REACTIONS (GEAR WEIGHT APPLIED AS ONE CONCENTRATED LOAD)

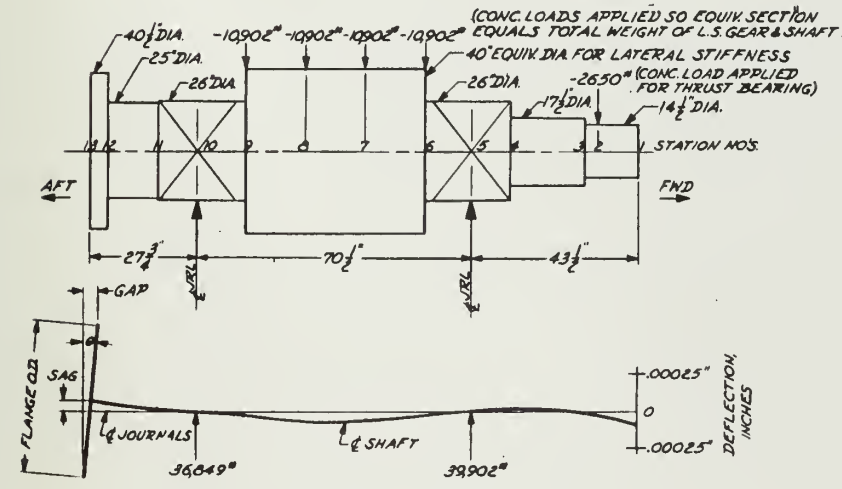


TABLE OF CALCULATED VALUES

STA NO	SLOPE (θ) (RADIANS)	DEFLECTION (INCHES)	CONC. LOAD(-) OR BRG. REAC.(+)
1	+.000006	-.000107	
2	+.000006	-.000046	-2650#
3	+.000005	-.000026	
4	-.000001	+.000024	
5	-.000003	0	39,902#
6	-.000002	-.000040	
7	-.000001	-.000067	
8	+.000001	-.000070	
9	+.000002	-.000045	
10	+.000004	0	36,849#
11	+.000003	+.000038	
12	+.000003	+.000075	
13	+.000003	+.000088	

AT END OF SHAFT

SAG = DEFLECTION AT STA #13 = +.00009
GAP = (FLANGE O.D.)(SIN θ)
SINCE θ = SIN θ FOR SMALL ANGLES
GAP = (FLANGE O.D.)(SLOPE AT STA #13)
GAP = (40.5")(.000003) = .00012"

Figure 9 - LOW SPEED GEAR DEFLECTIONS AND BEARING REACTIONS (GEAR WEIGHT APPLIED AS FOUR CONCENTRATED LOADS)

APPENDIX "H"

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APPENDIX "H"

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